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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

INCORPORATING AFEWC IMOM AS AN
INSTRUCTIONAL ASSET FOR NPS RADAR AND
ELECTRONIC WARFARE CURRICULA

by

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September 1992

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable) EC	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification) INCORPORATING AFEWC IMOM AS AN INSTRUCTIONAL ASSET FOR NPS RADAR AND ELECTRONIC WARFARE CURRICULA

12 PERSONAL AUTHOR(S) VAN SPLINTER, Gregg A.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	September 1992	124

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the US Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Electronic Order or Battle; Electronic Combat Mission Planning; Radar; Electronic Warfare; IMOM; EOB

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

In this thesis, effort is made to incorporate the computer program, Improved Many(Jammers)-on-Many(Radars) (IMOM), into radar and electronic warfare curricula at the Naval Postgraduate School. The IMOM program is used operationally by the U.S. Air Force for electronic combat mission planning. IMOM allows the user to evaluate electronic combat effects through computer color graphics display of the electronic order of battle including terrain effects.

This same program used in an academic role, provides students in radar and electronic warfare a tool for understanding radar principles, jamming principles, and the physical interaction between the two. The objective is to provide a visible link between radar range theory presented in coursework and the two-dimensional electronic combat scenarios presented by IMOM. This is done by plotting the theoretical results for radar

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL LEVIEN, Frederic	22b TELEPHONE (Include Area Code) 408-646-2476; 22c OFFICE SYMBOL EC/Lv

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603

UNCLASSIFIED

19. cont.

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Incorporating AFEWC IMOM as an Instructional Asset for NPS Radar and Electronic Warfare Curricula

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

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T3155 c.2

ABSTRACT

In this thesis, effort is made to incorporate the computer program, Improved Many(Jammers)-on-Many(Radars) (IMOM), into radar and electronic warfare curricula at the Naval Postgraduate School. The IMOM program is used operationally by the U.S. Air Force for electronic combat mission planning. IMOM allows the user to evaluate electronic combat effects through computer color graphics display of the electronic order of battle including terrain effects.

This same program used in an academic role, provides students in radar and electronic warfare a tool for understanding radar principles, jamming principles, and the physical interaction between the two. The objective is to provide a visible link between radar range theory presented in coursework and the two-dimensional electronic combat scenarios presented by IMOM. This is done by plotting the theoretical results for radar signal return, jammer return, and the jamming to signal ratio for both self protection and stand-off jammers. A MATLAB program is used to generate plots of the radar and jamming equations and to validate the IMOM algorithm against the equations used at NPS. The effect of radar parameter changes on the system is clearly displayed, both on the graphical MATLAB output and the IMOM graphics display, therefore enhancing the student's understanding of radar and jamming principles.

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TABLE OF SYMBOLS AND ABBREVIATIONS

°K	Degrees Kelvin
λ	Wavelength
μs	Microseconds
σ	Radar cross section
τ	Radar pulsewidth
AAA	Anti-Aircraft Artillery
AFEWC	Air Force Electronic Warfare Center
AGL	Above Ground Level
AWACS	Airborne Warning and Control System
B_r	Radar receiver or Doppler filter bandwidth
B_j	Jammer transmitted noise bandwidth
c	Speed of light, 3×10^8 m/s
dB	decibel
dBm	decibel relative to 1 mW
dBW	decibel relative to 1 W
DOS	Computer operating system
EC	Electronic Combat
ECE	Electronic and Computer Engineering
ECM	Electronic Countermeasures
$E_i(n)$	Radar postdetection integration efficiency
ELINT	Electronic Intelligence
ELNOT	Electronic Intelligence Notation
EOB	Electronic Order of Battle
ERP	Effective Radiated Power
EW	Early Warning or Electronic Warfare
FC	Fire Control
f	RF frequency
F_n	Radar receiver Noise Figure
GHz	Gigahertz
G_j	Jammer transmit antenna gain
G_{ja}	Jammer amplifier gain
G_{jr}	Jammer receive antenna gain
G_r	Radar receive antenna gain
G_t	Radar transmit antenna gain
HF	Height Finder
HIPNT	High Point
HP LaserJet XL	Color plotter
Hz	Hertz
I	Radar integration Improvement Factor
IMOM	Improved Many-on-Many
J/S	Jamming to Signal Ratio
J_{BL}	SOJ jamming signal in radar backlobe
J_{CG}	Constant gain jamming signal
J_{CP}	Constant power jamming signal
J_{ML}	SOJ jamming signal in radar mainlobe
JPA	Jammer Planning Aid
J_{SL}	SOJ jamming signal in radar sidelobe
k	Boltzmann Constant, 1.38×10^{-23} J/°K
km	Kilometer
kW	Kilowatt

Lat	Latitude
L_{jr}	Jammer receive line loss
L_{jt}	Jammer transmit line loss
Long	Longitude
LOS	Line-of-Site
L_r	Radar receive line loss
L_t	Radar transmit line loss
m	Meter
m^2	Square meters
MDS	Minimum Detectable Signal
MHz	Megahertz
MSL	Mean Sea Level
mW	Milliwatt
nmi	Nautical Miles
P_{AV}	Radar average transmitted power
P_j or P_{jTWTA}	Jammer amplifier power output
P_{PK}	Radar peak transmitted power
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
P_t	Radar transmit power at antenna terminal
R_t	Range to target aircraft
RCS	Radar Cross Section
RF	Radio Frequency
R_j	Range to jammer aircraft
R_{max}	Range maximum detection range
R_{mds}	Range at minimum detectable signal
R_{sat}	Range at jammer amplifier saturation
R_U	Radar unambiguous detection range
s	Seconds
S/N	Signal to Noise Ratio
S	Radar signal return
SAM	Surface-to-Air Missile
S_{mds}	Minimum detectable signal level
SOJ	Stand-off Jammer
SPJ	Self-protection Jammer
T	Radar receiver temperature (degrees K)
TA	Target Acquisition
TER	Terrain
TT	Target Tracker
Unix	Computer operating system
US	United States
W	Watt

ACKNOWLEDGEMENT

I wish to express thanks to the Advanced Modelling Division, AFEWC, especially Jack Ridgeway, Capt. Scott Owens, and Chris Barsalau, for their technical assistance and answers to many questions during the process of incorporating IMOM at NPS. Also, thanks to Lt. Col. Thomas White, without whom NPS would not have the IMOM computer program.

Special thanks to my advisor, Professor Fred Levien, for providing the opportunity to utilize IMOM as a thesis topic and to produce something that will benefit NPS Radar and EW. In addition, this thesis was accomplished with the technical assistance of Paul Buczynski, ECE Radar/EW laboratory technician.

I want to thank Mr. James E. Hobson, Division Head, Vulnerability Assessment Division, NAWC/WPN, without whose approval I would not have had the opportunity to pursue my M.S.E.E. at NPS. I would also like to thank all of the DLQ crew, especially Phil Spratt, who took over my workload during my year away at NPS.

Thank you to Karen Callaghan who produced the final printed version of this thesis.

I want to express appreciation to my wife, Tiffani, for her encouragement and understanding during many hours apart during my studies at NPS.

I. INTRODUCTION

A. PURPOSE

This thesis illustrates the use of computer program, Improved Many(Jammers)-on-Many(Radars) (IMOM), as a teaching tool for the Radar and Electronic Warfare (EW) curricula at the Naval Postgraduate School (NPS). This program was developed by the U.S. Air Force Electronic Warfare Center (AFEWC) for electronic combat (EC) mission planning. Students currently taking radar and EW courses are exposed to the basic principles and supporting mathematical analysis. Numerical computation of system performance is performed in coursework and actual radar and EW system operational characteristics are presented in laboratory work.

Due to limited course offering in radar and EW, students are presented a wide array of material in a single academic quarter time frame, with limited time to cover some important aspects in detail. The objective of using IMOM is to provide a physical display of the principles presented, thereby allowing the student to see, by computer graphics, the radar characteristics and jamming effectiveness. This is only one aspect of IMOM. Additional IMOM benefits are covered later when IMOM utilization is presented.

This thesis is structured to supplement and enhance the radar and EW coursework at the Naval Postgraduate School.

Utilizing this thesis, a student can expect to gain understanding of the required radar concepts that are the basis to any further involvement in radar or EW systems.

B. STRUCTURE

The thesis is structured with six primary sections. These sections are; Requirement: Curricula Enhancement, Radar Theory: Radar Range Equation, IMOM Description, IMOM Utilization, Radar Exercises, and Electronic Warfare Exercises.

Chapter II, the Requirement section, describes the benefit of IMOM as part of the radar and EW curricula. The features that make IMOM applicable are briefly introduced here and described in detail in the sections that follow.

The Radar Theory section, Chapter III, provides a review of applicable radar range theory that is presented in all entry level radar courses. This section is further subdivided into radar maximum detection range, radar signal return and jamming considerations. The goal of this chapter is to strengthen the foundations of radar signal theory, and compare theoretical results with the graphics display output of the IMOM model. Validation of the IMOM computer graphics is also achieved by analyzing the theoretical results. This will enhance student knowledge required in coursework, since the IMOM model is based on the same equations taught in the coursework.

A description of IMOM in Chapter IV follows the radar theory section, explaining the information it provides that is applicable to NPS radar and EW curricula. In addition, utilization of IMOM by the U.S Air Force for mission planning is described.

Chapter V which follows suggests how IMOM can be used to further enhance Radar and EW coursework at NPS. Direct relationships between the radar theory presented earlier and the two-dimensional display offered by IMOM is explored. The interrelationship of radar characteristics, jamming characteristics and the effectiveness of jamming on a radar is explained. The jamming effectiveness is assessed utilizing many real world situations in the IMOM model.

Samples of radar and jamming exercises are next presented in Chapters VI and VII, the Radar Exercises and Electronic Warfare Exercises sections. These sections show the utility of IMOM in the NPS radar and EW curricula.

II. REQUIREMENT: CURRICULA ENHANCEMENT

This chapter demonstrates how the AFEWC IMOM program can act as a tool in the teaching of radar and EW at NPS.

A. RADAR

The Naval Postgraduate School currently offers only one entry level radar course to students. The course that is taken depends upon each student's individual curriculum. The current courses are as follows:

EC3760	Principles of Radar Systems
EC4610	Radar Systems (US)
EC4620	Radar Systems (International)
EO4760	Microwave Devices and Radar Systems

The course, EC3760, is structured for Avionics and Weapons curriculum students, EC4610 for U.S. ECE curriculum students, EO4760 for U.S. non-ECE students, and EC4620 for international students. Although these are four separate courses, with slightly different objectives, all basically present the students with the same radar theory required. Recently, NPS did offer a follow-on radar course, EC4970, Radar Signal Processing, during the Spring Quarter, 1992. The Radar Signal Processing course is also scheduled for the NPS Fall academic quarter during the FY93 school year.

Regardless of which course is taken, the basic radar theory must be presented as just one small part of the course. Time spent to understand these important concepts is at a

premium. A student's time is divided between course lecture, homework calculations, laboratory assignments, and project reports. An additional instructional tool such as IMOM would enhance understanding of principles in the allotted time.

Graphical plots of theoretical data, generated by a MATLAB program developed in this thesis, and IMOM displays, together enhance the student's ability to comprehend radar theory and related operating parameters.

B. ELECTRONIC WARFARE

NPS offers only one EW course to students. Like the radar courses, a separate course is taken depending upon each student's curriculum. The current EW courses are as follows:

EO3780	Electronic Warfare Computer Applications
EC4670	Electronic Warfare
EC4680	Electronic Warfare Techniques and Systems
EC4690	Principles of Electronic Warfare Systems
EO4780	Electronic Warfare Systems

With the exception of EO3780, the other four courses are quite similar in that they present general principles of EW. The course EO3780 is structured for Avionics and Weapons curriculum students, EC4670 for U.S. non-ECE curriculum students, EO4680 for U.S. ECE students, EC4690 for international ECE students and EO4780 for U.S. non-ECE students. Although these are five separate courses, all present the students with the same basic EW theory required to understand radar and jamming interaction.

The basic jamming equation theory is presented as just one small part of each EW course. Time spent to understand these important concepts is again at a premium. A student's time is divided the same as for radar. An additional instructional tool such as IMOM can increase understanding of jamming principles.

As with the radar, graphical plots of theoretical data generated by the MATLAB program, and IMOM displays, together enhance the student's ability to comprehend jamming effectiveness against a radar.

It is hoped that the material provided in this thesis will increase the students ability to absorb the Radar and EW concepts presented both in class and in the laboratory.

III. RADAR THEORY: RADAR RANGE EQUATION

The radar range equation is the fundamental basis for all radar directed studies. The basic radar equations will not be derived here since all are thoroughly covered in courses at NPS and can be found in radar textbooks as well (see e.g., [1]. The appropriate radar parameters and related equations used in the IMOM model will, however, be summarized. The equations are presented since IMOM utilizes the same equation to determine the display characteristics of the radars in an electronic order of battle (EOB).

A. RADAR

All radars can be characterized by their particular operating parameters. This thesis will define the radar parameters used in the radar range equation to calculate the theoretical performance of any radar. Each parameter is introduced and a brief description of the function it performs in the radar follows. After the parameters are summarized, the specific radar performance equation is shown utilizing the given parameters. The radar performance characteristics calculated are the radar maximum detection range and the radar signal return from an aircraft target.

1. Radar Parameters

The primary radar parameters utilized in the radar range calculations are summarized in Table 1. Each of the

parameters listed is used in the corresponding radar equations to follow.

TABLE 1	
RADAR PARAMETERS	
λ	Wavelength
B_r	Receiver or Doppler Filter bandwidth
$E_i(n)$	Postdetection integration efficiency
F_n	Receiver Noise Figure
G_r	Receive antenna gain
G_t	Transmit antenna gain
k	1.38×10^{-23} J/°K (Boltzmann constant)
L_r	Receive line loss
L_t	Transmit line loss
P_{AV}	Average transmit power
P_{PK}	Peak transmit power
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
τ	Pulse width
P_t	Transmit power at antenna terminal
R_t	Range to target aircraft
S/N	Signal to Noise Ratio
T	Receiver temperature (°K)
I	Integration Improvement Factor

Some of the basic mathematical relationships of the radar parameters must first be discussed. The wavelength of the transmitted radar energy is calculated from the radar operating frequency:

$$\lambda = \frac{c}{f} \qquad (1)$$

The operating frequency of a radar is chosen depending on the primary function of the radar. The types of radars associated with IMOM are listed in Table 2. Typically, EW and HF types of radars operate in the lower radar frequency bands (L, S, and C) and are scanning types of radars. The TA, TT, and FC radars typically operate at higher frequencies (C, X and K_u band), have small antenna beams, and provide single target track. In addition, TT and FC radars generally have an associated weapon system, such as an anti-aircraft artillery gun (AAA) or surface-to-air missile (SAM) battery.

TABLE 2

IMOM RADAR TYPES

HF	Height Finder
EW	Early Warning
TA	Target Acquisition
TT	Target Tracker
FC	Fire Control

Each radar is also characterized by its PRI, or its PRF, and its pulse width. The pulse width can also be approximated from the radar bandwidth by:

$$\tau = \frac{1}{B_r} \tag{2}$$

The radar bandwidth is taken to be the receiver bandwidth or more specifically the bandwidth of the receiver doppler filter (expressed in Hz).

The unambiguous radar range is related to the radar PRF by:

$$PRF = \frac{c}{2R_U} \tag{3}$$

where c is the velocity of light.

Pulsewidth and PRF are also used to calculate the average transmit power of the radar if the radar transmit power is given as peak power. The relationship between peak and average power is:

$$P_{AV} = P_{PK} \tau PRF \tag{4}$$

Another key equation involved in using the radar equation is determination of the radar receiver noise. The noise in the receiver is important since the signal to noise ratio (S/N) defines the minimum detectable signal required for the radar to function properly. The noise is characterized by the receiver bandwidth, temperature, and noise figure. The noise figure is used as a figure of merit for a particular receiver. The receiver noise can be determined by:

$$N=kTB_IF_n \tag{5}$$

If pulse integration is used in the radar for target detection, then the radar range equation must be further modified. The detection range of a radar is increased if pulses are integrated. An integration improvement factor (I) is added to the range equation when taking this into account. The improvement factor is defined in terms of an integration efficiency, S/N for one pulse, and S/N for multiple pulses [1]. The integration improvement factor (I) is defined as:

$$I=nE_i(n) \tag{6}$$

where $E_i(n) = (S/N)_1/n(S/N)_n$. To be used in the range equation when pulse integration is utilized, the S/N for n pulses is expressed in terms of I and S/N for one pulse. This is shown below in the maximum detection range calculation.

2. Maximum Detection Range

The maximum radar detection range can now be defined in terms of the given radar parameters. The maximum detection range is a function of the radar transmit peak power, transmit antenna gain, receive antenna gain, line and propagation losses, receiver noise, target echo, and integration improvement factor. The maximum detection range is:

$$R_{max}=\left[\frac{P_t G_t G_r \lambda^2 \sigma I}{(4\pi)^3 \left(\frac{S}{N}\right)_1 kTB_r F_n L_t L_r}\right]^{\frac{1}{4}} \tag{7}$$

Line of sight (LOS) is another factor limiting radar maximum detection range. The radar may be horizon limited in its detection capability. The geometry of horizon limitation depends upon the radar antenna height and the target aircraft altitude. The horizon limited range assuming flat terrain is given by;

$$R_h(meters) = \sqrt{2h_r r_e}+\sqrt{2h_t r_e} \tag{8}$$

where the height of the radar antenna, h_r, and the altitude of the target, h_t, are given in meters. The radius of the earth, r_e, is given as 8.5×10^6m.

3. Radar Signal Return

Normally, the radar cross section (RCS) of a target fluctuates as defined by one of Swerling Case models [1]. Here, radar cross section, σ, is assumed to be from a constant RCS target. The signal return is required in order to calculate the jamming to signal ratio. The target signal return can be calculated by:

$$S=\frac{P_t G_t G_r \lambda^2 \sigma I}{(4\pi)^3 R_t^4 L_r} \tag{9}$$

B. JAMMER

All jammers can also be characterized by their particular operating parameters. The jammer parameters used in the jamming equations to calculate the theoretical performance of a jammer is presented here. The reason for presenting the jamming equations is that IMOM utilizes the same equations to calculate SOJ effectiveness against the given radars in an EOB.

Self protection jamming (SPJ) and stand off jamming (SOJ) equations are shown utilizing the given jammer parameters. Three jammer performance characteristics are calculated: (1) the jamming signal from a noise jammer (SPJ) on the target aircraft, (2) deception jammer signal return (SPJ), and (3) jamming to signal (J/S) ratios for SPJ and SOJ targets.

Two primary types of jamming exist; *noise and deception.* The objective of noise jamming, or denial jamming, is to completely obscure or deny any actual target return signal to the hostile radar receiver. An advantage to noise jamming is that only a minimum of information needs to be known about the victim radar for jamming to be effective. A disadvantage of the noise jammer is that it requires a high effective radiated power (ERP) since the bandwidth of the noise is usually wider than the radar receiver bandwidth [2].

The objective of deception jamming is to mask the actual target return or modify the target return in order to confuse or prevent detection by a hostile radar. The advantage of

deception jamming is that a lower ERP is required. A possible disadvantage is that the jammer must be activated at an optimum time, not always easily calculable, in order to prevent detection as well as not enhancing detection by becoming a beacon [2].

It is important to be able to distinguish between noise and deception jamming when performing jammer effectiveness analysis. This is because the jammer signal level at the radar depends upon what type of jamming is being utilized, noise or repeater, as well as what role the jammer is tasked to fulfill, either SPJ or SOJ. A deception jammer can operate in two distinct modes; constant power (CP) output or constant gain (CG) output. An explanation of the difference between the two is presented in the Deception Jammer Signal section.

1. Jammer Parameters

The primary jammer parameters utilized in the jammer signal calculations to be examined are summarized in Table 3. Each of the parameters listed is used in the corresponding jamming equations to follow.

TABLE 3	
JAMMER PARAMETERS	
B_j	Noise bandwidth
G_j	Transmit antenna gain
G_{ja}	Amplifier gain
G_{jr}	Receive antenna gain
J_{BL}	SOJ signal in radar backlobe
J_{CG}	Constant gain deception jamming signal
J_{CP}	Constant power deception jamming signal
J_{ML}	SOJ signal in radar mainlobe
J_{SL}	SOJ signal in radar sidelobe
L_{jr}	Receive line loss
L_{jt}	Transmit line loss
P_j or P_{j-TWTA}	Amplifier saturated power output
R_j	Range to SOJ Jammer aircraft
S_{MDS}	Minimum detectable signal at jammer

2. Jammer Minimum Detectable Signal

In order for the jammer to determine if jamming is required, the jammer must detect the radar signal. A jammer receiver usually has a specified minimum detectable signal (MDS) which defines when the jammer can detect the radar signal. IMOM calculates the radar signal at the jammer and compares this value to the S_{MDS} specified for the jammer receiver. Jamming effectiveness is evaluated if the jammer can detect the radar signal. The signal at the jammer, labeled S_{MDS} here, is calculated from:

$$S_{mds}=\frac{P_t G_t G_{jr} \lambda^2}{(4\pi)^2 L_{jr} R_j^2} \tag{10}$$

3. Self Protection Jamming

Self protection jamming (SPJ) is so defined because the jammer is located on the aircraft to be protected. This is generally done to provide the optimum protection for the aircraft against hostile weapon systems. Self protection jammers use the ERP more efficiently against a hostile radar since the jamming signal is injected into the radar main beam. This is one reason SPJ utilizes deceptive jamming more effectively [2].

a. Noise Jammer Signal

The SPJ noise jamming signal has the advantage over the radar target echo in that it only has to travel in one direction. Therefore, the space loss associated with the jammer signal is related only to the square of the range. The jammer signal level must also be adjusted by including a bandwidth factor. The jamming power injected into a victim radar depends upon the ratio of the radar receiver bandwidth to the jammer transmitted noise bandwidth. The jamming equation for the SPJ noise jamming signal received by the victim radar is:

$$J=\frac{P_j G_j G_r \lambda^2}{(4\pi)^2 L_r L_{jt} R_t^2}\left(\frac{B_r}{B_j}\right) \tag{11}$$

b. Deception Jammer Signal

The same propagation laws that applied to SPJ noise jamming also apply to deception jamming. However, in this case the jammer output ERP is not constant for all ranges from the radar. In deception jamming, the radar signal is received, amplified, modulated, and retransmitted to mask the true target echo. The deception jammer operates in two distinct transmit modes depending upon the range to the radar and the operating parameters of both the radar and the jammer. Namely constant gain and constant power output [3]. This is in contrast to noise jamming which normally operates in saturation, or at maximum output power.

The range at which the jammer switches from constant gain to constant power is called the saturation range. This is the point where the radar signal received at the jammer is sufficient to drive the jammer output amplifier to it maximum output level. The saturation range is given as:

$$R_{sat}=\left[\frac{P_t G_t G_{jr} G_{ja} \lambda^2}{(4\pi)^2 P_{j_{TWTA}} L_{jr}}\right]^{\frac{1}{2}} \tag{12}$$

For radar to jammer range greater than the saturation range (called "constant gain" region), the jammer signal at the radar receiver is given by:

$$J_{CG}=\frac{P_t G_t G_r \lambda^4 G_{jr} G_{ja} G_j}{(4\pi)^4 R_t^4 L_r L_{jr} L_{jt}} \tag{13}$$

For radar to jammer range less than the saturation range (called "constant power" region), the jammer signal at the radar receiver is given by:

$$J_{CP}=\frac{P_{j_{TWTA}}G_jG_r\lambda^2}{(4\pi)^2R_t^2L_rL_{jt}} \tag{14}$$

c. Self Protection Jamming to Signal Ratio

The jamming to signal ratio (J/S) for a jammer versus a radar is generally the factor utilized to determine jammer effectiveness. This J/S determines at what range a radar can detect a target through a jamming signal. This range is referred to as the "burnthrough" range for the radar. The exact range where burnthrough occurs is a function of the radar mode of operation and the jammer electronic countermeasure (ECM) technique utilized. Therefore, it is not an absolute number. Radar burnthrough range can be estimated by defining a required J/S for the particular jammer technique utilized.

The J/S ratio for noise SPJ on the target aircraft versus range is given by:

$$\frac{J}{S}=\frac{P_jG_j4\pi R_t^2}{P_tG_t\sigma IL_{jt}}\left(\frac{B_r}{B_j}\right) \tag{15}$$

The J/S ratio for deception SPJ on the target aircraft versus range depends upon whether the target aircraft is less than or

greater than the jammer saturation range. For range greater than the saturation, the J/S ratio is given by:

$$\frac{J_{CG}}{S}=\frac{\lambda^2 G_{jr} G_{ja} G_j}{4\pi L_{jr} L_{jt} \sigma I} \tag{16}$$

For range less than saturation, the J/S ratio is given by:

$$\frac{J_{CP}}{S}=\frac{P_j G_j 4\pi R_t^2}{P_t G_t \sigma L_{jr} I} \tag{17}$$

Important to note from equation 16 is that the J/S ratio calculated is constant for range greater than saturation. This is due to the range relationship of the jamming signal as shown in equations 13 and 14. The jamming signal is proportional to $1/R^2$ for range less than saturation and $1/R^4$ otherwise.

4. Stand-Off Jamming

Stand-off jamming (SOJ) refers to when the jammer is carried on an aircraft other than the attacking aircraft. Present U.S. tactics call for the SOJ aircraft generally to be placed outside the lethal range of any hostile weapon systems. The objective is to provide ECM to screen one or more attacking aircraft. This geometry of a stand-off jammer scenario requires the most efficient use of the jammer ERP in order to affect all required victim radars.[2]

The geometry of the SOJ relative to the radar can basically be defined in terms of mainlobe, sidelobe, and backlobe jamming. The difference between the jamming signal in these three cases is the amount of jammer ERP required due to the difference in the radar antenna gain between the mainlobe, sidelobe, and backlobe.

a. Noise Jammer Signal

The noise jamming signal for SOJ is calculated the same as for SPJ, using equation 11. The only difference for the SOJ is in the range, R, and the antenna gain, G_r. The range to the SOJ is assumed to be constant, or that the SOJ is at a fixed range from the radar. This is the scenario utilized by IMOM when modelling SOJ effectiveness. The value of G_r is dependent upon the SOJ-to-radar geometry. G_r is either the gain of the radar mainlobe, sidelobe, or backlobe. The effect of the difference in gain will be apparent in the SOJ J/S equations.

b. Deception Jammer Signal

Deception jamming is not usually provided by a stand-off jammer (SOJ). If deception jamming is to be provided by the SOJ, the jamming signal would be calculated the same as for SPJ deception jamming signal (see equations 13 and 14). The same range and radar antenna gain considerations for noise jamming apply to the deception jamming equations.

c. Stand-off Jamming to Signal Ratio

The J/S ratio for SOJ is defined exactly as that for SPJ. Radar burnthrough is estimated by the range at which a specific J/S occurs. The difference in J/S between SPJ and SOJ is that the range used to calculate the jammer signal is assumed to be fixed for SOJ. Therefore, the range is affected by the range relationship R_t^4/R_j^2, where R_j is constant and R_t varies as the target aircraft approaches the radar. The J/S calculation also depends upon the ratio of the radar sidelobe gain or backlobe gain to the mainlobe gain when the SOJ is not located in the radar antenna mainlobe.

The SOJ J/S ratio for in the victim radar mainlobe is given by:

$$\frac{J_{ML}}{S} = \frac{P_j G_j 4\pi}{P_t G_t \sigma L_{jt} I}\left(\frac{B_r}{B_j}\right)\left(\frac{R_t^4}{R_j^2}\right) \qquad (18)$$

The SOJ J/S ratio for jamming in the victim radar sidelobe and backlobe are given in equations 19 and 20 respectively. The only difference is the radar antenna gain factor that affects how much jamming power enters the radar. This directly affects the required ERP of the SOJ if the same J/S is applied to each of the three SOJ geometries, mainlobe, sidelobe, and backlobe.

$$\frac{J_{SL}}{S} = \frac{P_j G_j 4\pi}{P_t G_t \sigma L_{jt} I}\left(\frac{B_r}{B_j}\right)\left(\frac{R_t^4}{R_j^2}\right)\left(\frac{G_{SL}}{G_{ML}}\right) \qquad (19)$$

$$\frac{J_{BL}}{S} = \frac{P_j G_j 4\pi}{P_t G_t \sigma L_{jt} I} \left(\frac{B_r}{B_j} \right) \left(\frac{R_t^4}{R_j^2} \right) \left(\frac{G_{BL}}{G_{MC}} \right) \tag{20}$$

The radar and jamming equations are presented in this chapter to provide the fundamental principles used by IMOM to create a display of radar detection capabilities. In addition, the results calculated from the equations served to validate the IMOM displayed radar capabilities.

IV. IMOM DESCRIPTION

This chapter describes IMOM in detail with respect to its application to NPS radar and EW curricula. IMOM is a computer program that displays radar coverage, including the effects of terrain, jamming and associated weapon system envelopes, in order to model an electronic order of battle [4]. The Air Force utilizes IMOM as an operational electronic combat mission planning system [4]. IMOM Unix version 2.3 is utilized in this thesis, operating on NPS Sun Microsystems SPARC Workstation.

Many aspects of radar, jamming and other order of battle environment characteristics can be modelled and displayed by IMOM. These display characteristics are directly applicable to enhancing NPS radar and EW coursework. For example, displaying a radars detection envelope, with or without terrain masking effects, can be used to illustrate the radars operating characteristics. The detection characteristics can be validated by the theory presented in Chapter II. In addition, if the radar modelled is associated with a weapon system, the radar display is modified according to the weapon system envelope characteristics.

The radar envelope can also be displayed with the effects of self protection jamming, stand-off jamming, or both. Thus, the interaction of the jammers with the radars can be illustrated. The burnthrough ranges of the radars versus

jammers in the EOB can be compared to jammer equation calculations covered. Self protection jamming is assumed to be on the attack aircraft whose flight path is entered by the user. Any number of stand-off jammers can be added to the EOB, and are also positioned by the user. Thus, a student can view in color graphics the effect of jamming on a radar, and therefore determine an optimum SOJ position.

IMOM is not limited to just radar and jammers, but includes many other aspects, some of which are shown in Table 4. IMOM is capable of modelling the electronic order of battle for an entire geographical, or geopolitical, area specified by the user from the available terrain database.

TABLE 4
SAMPLE OF ADDITIONAL IMOM FEATURES
SOJ orbits
Threat airfields and combat radius of aircraft stationed there.
Ground troop formations
Battlefield markers: targets, WFZ, FLOT, ROZ
SEAD HARM weapon envelope capabilities
MAP capabilities
Line of Site display characteristics to individual ROUTE positions

Since the scope of IMOM attributes is so varied, only the radar, SPJ and SOJ aspects of the program are exercised for this thesis.

A. U.S. AIR FORCE IMOM APPLICATIONS

IMOM plays a key role in numerous Air Force operational exercises, including RED FLAG, GREEN FLAG, and BLUE FLAG for example. It provides the Blue force commanders with near real time display of the enemy order of battle as comprised by intelligence sources [5].

Intelligence planners use IMOM to support aircrew mission planning and threat assessment. IMOM displays the threat presented to an aircraft throughout its flight path, and creates point by point data files listing the threat analysis. Training and targeting are other aspects where IMOM is applied.[4]

The biggest asset of IMOM is the capability for the operator to interface with the program and conduct "what if" scenarios. This has great academic applications, since many principles can be presented by conducting "what if" profiles in IMOM and reviewing the results. Therefore any radar and jammer parameters can be modified, as well as jammer placement, and the results observed on the display. These results can then be compared to theoretical calculations for verification. Examples of these features are covered in the next section.

B. INFORMATION PRESENTED BY IMOM

This section summarizes the IMOM display attributes that are directly applicable to radar and EW directed studies.

This is not a list of all information IMOM is capable of displaying as shown in Table 4.

1. Radar

The IMOM "RINGS" feature allows the user to observe the radar detection capabilities. RINGS displays color coded radials emanating from the radar location, with the color signifying the detection capability of the radar and the length showing the detection range. For example, for EW, HF and TA radars, blue radials mean 100% detection by the radar is likely. These radials are red for a radar with an associated weapon system. A RINGS display without terrain masking or jamming is shown in Figure 1. The geographical location is the U.S. Air Force Nellis Test Range, Nevada. This will be the terrain database utilized for all work in this thesis. The color coding for jamming effectiveness will be discussed in sections 2 through 5 of this chapter.

The maximum detection range of each radar in an order of battle is displayed when "RUN RINGS" is selected from the RINGS main menu. The maximum detection range displayed by the radials for a particular radar depends upon five criteria. The maximum radial length is selected from the minimum of the following: calculated maximum detection range, R_{max}; horizon limited line of sight (LOS) range, R_h; maximum scope range; unambiguous range; and weapon range from selected weapon system. In the case of an associated

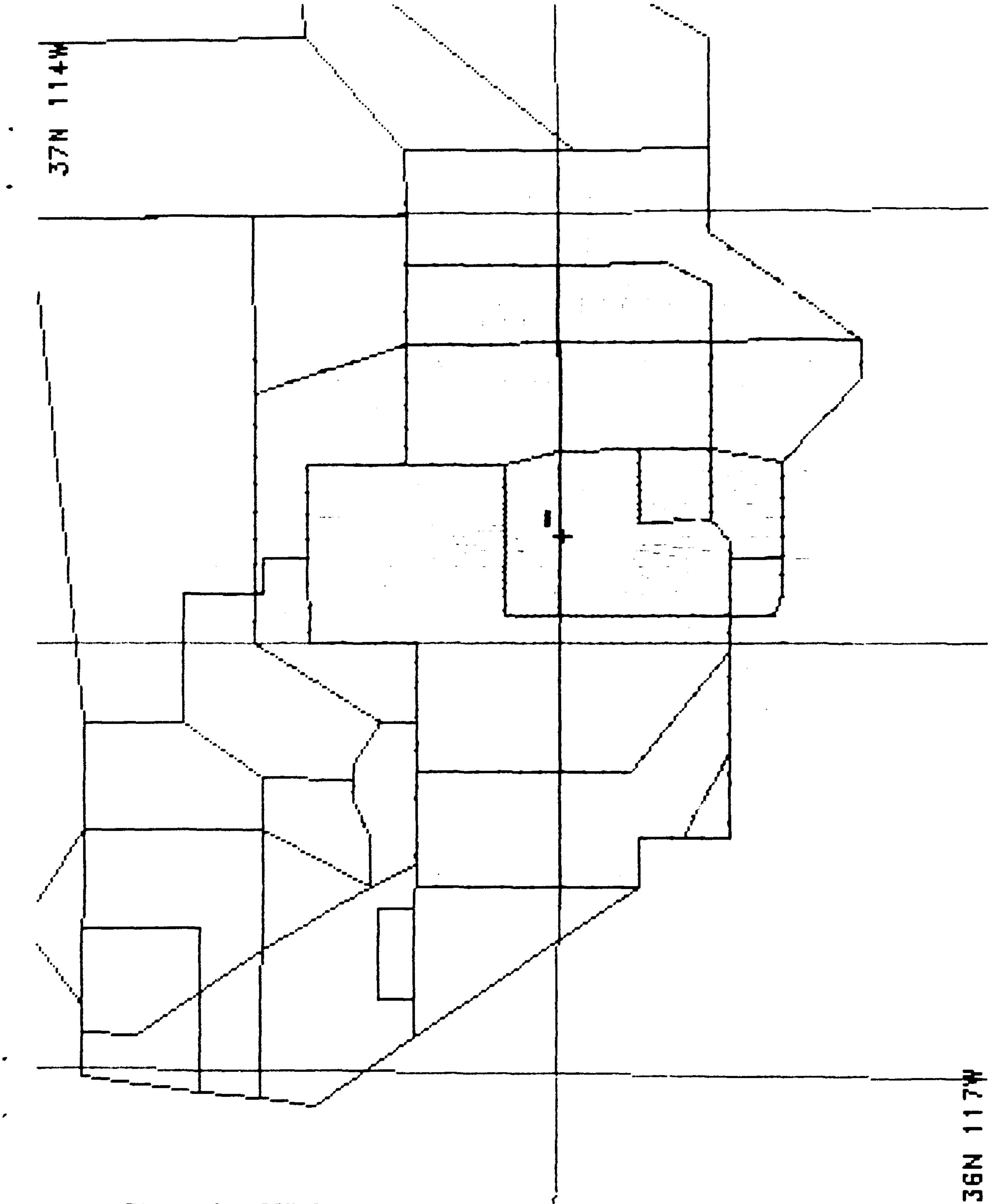

Figure 1. RINGS radar detection radials with no terrain or jamming effects.

weapon system, the maximum radial length is limited to the maximum range of the weapon at the user specified target altitude, rather than the capability of the radar. Figure 2 shows the same radar as that in Figure 1, with a weapon system envelope displayed in red. The maximum length of the blue radials in Figure 2 show what would normally be the detection range of the radar, and the red radials in Figure 2 show the weapon envelope. In the case of a TT or FC radar, the blue radials would not be displayed. Figure 2 shows the blue radials for reference only.

IMOM allows the user to select a radar with an associated weapon, or select the weapon directly to place in the EOB. To place a radar, with or without a weapon, the user selects "ELNOT" when adding a radar to the EOB. To place a weapon directly, the user selects "WEAPON" from the IMOM menu bar.

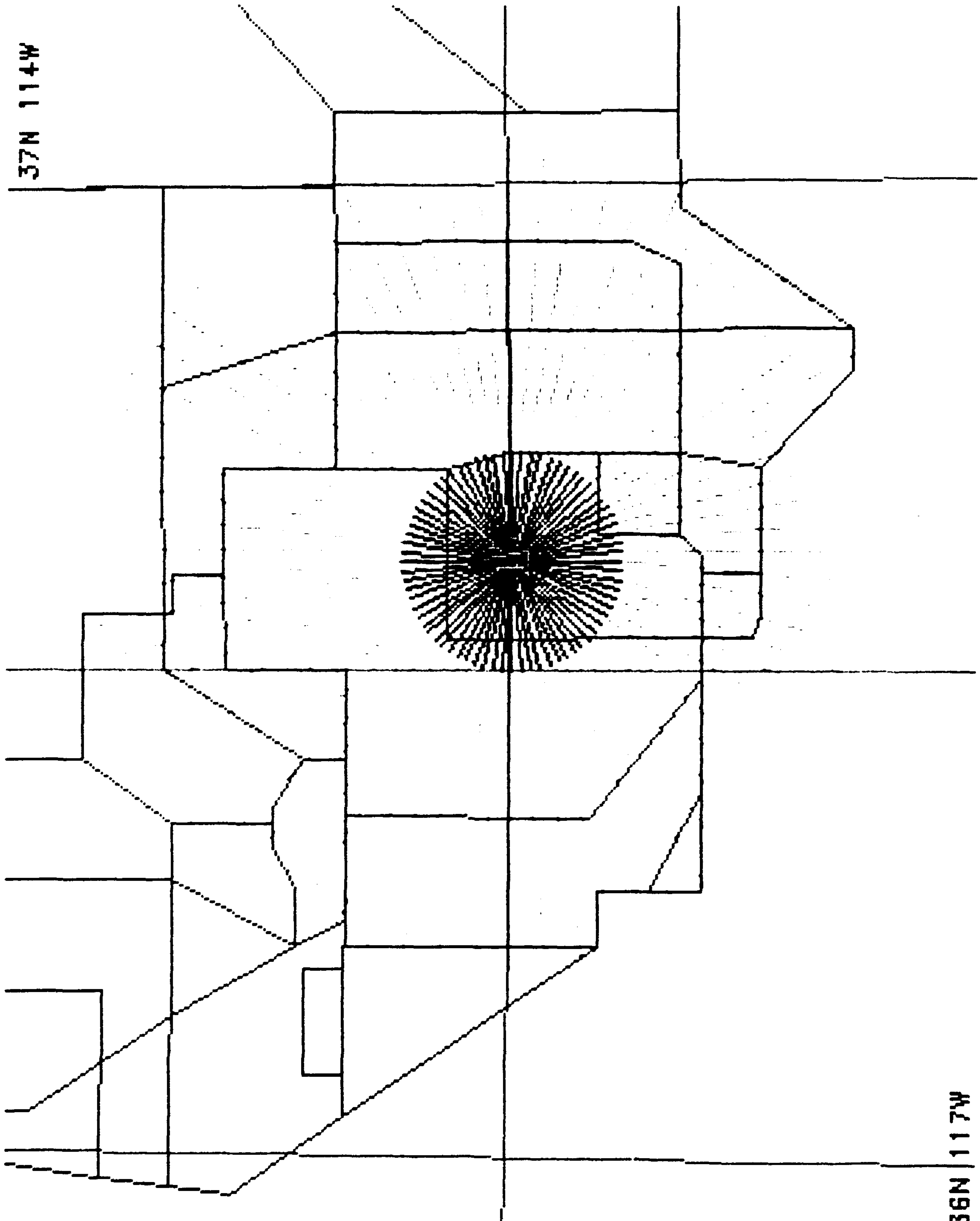

Figure 2. Weapon envelope (red) compared to radar detection envelope (blue)

2. SPJ

The color of the radials also changes depending upon the effectiveness of SPJ against the particular radar. As defined in IMOM, SPJ affects the RINGS display weapon envelopes for TT and FC radars. The color of the radials are yellow if the SPJ is 30-70% effective in degrading the radars lock-on capability. The radials are gray if the jammer is 70-100% effective in preventing radar lock-on. Red radials imply no jamming effectiveness. Figure 3 shows three radars, each with an associated weapon system, degraded by the SPJ as listed above. The triangles represent the flight path of the SPJ aircraft produced by the IMOM "ROUTE" feature. ROUTE is discussed in sub-section 10.

The SPJ effectiveness data accessed by IMOM is stored in the file SPJ_880129.DAT in the HOME/imom/data/imom/spj directory, where HOME depends on how the computer system is organized. A sample of how the data appears in the SPJ data file is shown in Figure 4.

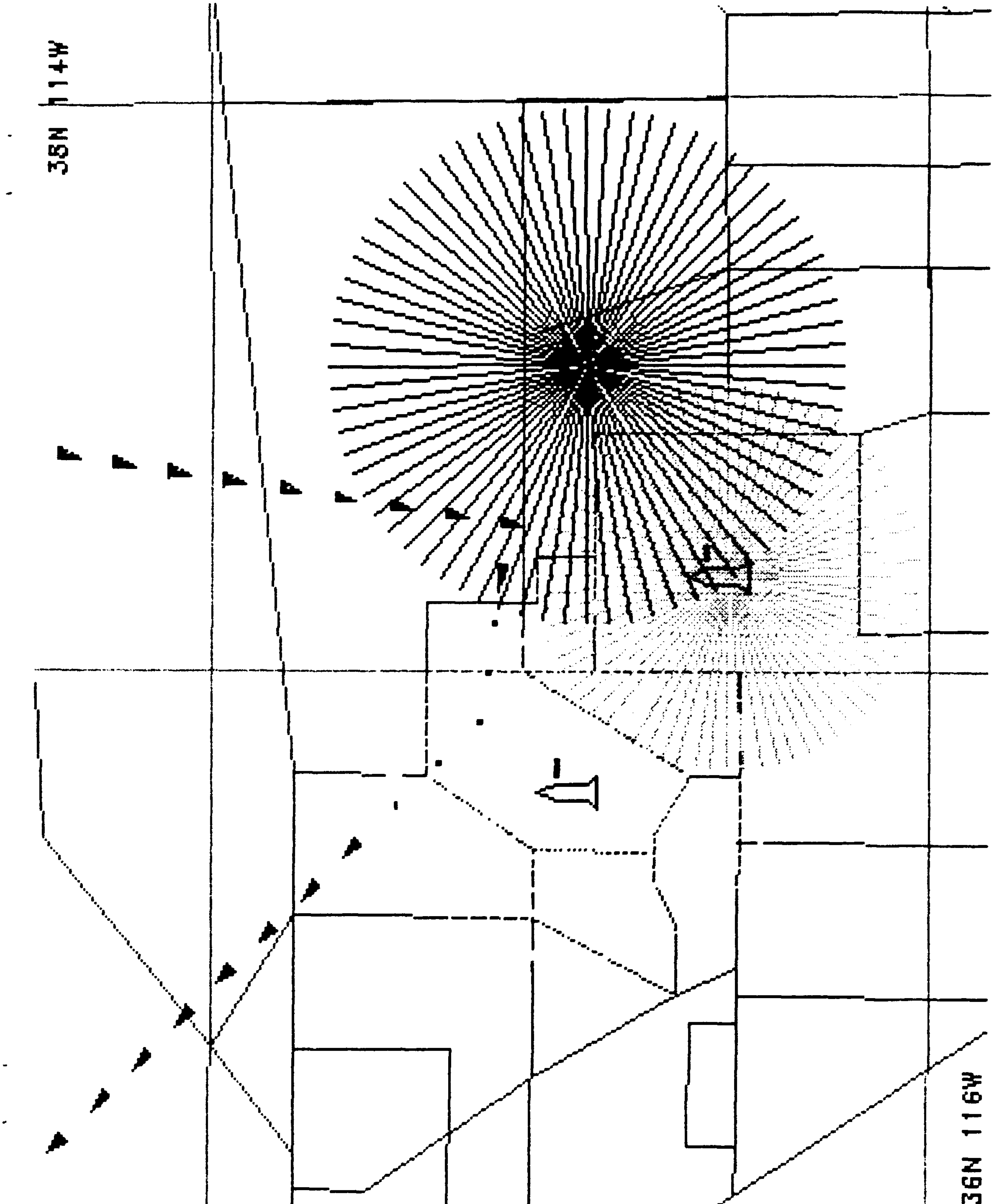

Figure 3. SPJ effect on three TT radars.

(1) A/C	(2) JAMMER	(3) WEAPON	(4) ALT.	(5) YY	(6) YN	(7) NY	(8) NN
F50	ALQ210	FATB	490	2	3	2	2FFFFFFFFF
F50	ALQ210	GUNN	10	1	1	1	1FFFFFFFFF
F50	ALQ210	UNC1	330	2	2	1	1FFFFFFFFF
F50	ALQ210	UNC2	165	1	2	1	2FFFFFFFFF
F50	ALQ210	UNC3	900	3	3	2	2FFFFFFFFF
F50	ALQ210	UNC4	100	3	3	2	2FFFFFFFFF
F50	ALQ210	UNC5	130	2	3	1	2FFFFFFFFF
F18	ALQ126	GUNN	10	1	1	1	1FFFFFFFFF
F18	ALQ165	UNC3	900	3	2	1	1FFFFFFFFF
A-6	ALQ165	UNC1	330	2	1	1	1FFFFFFFFF
A-6	ALQ126	UNC3	900	3	2	1	1FFFFFFFFF
A-6	ALQ126	UNC3	900	3	3	1	1FFFFFFFFF
A-6	ALQ165	UNC3	900	3	3	1	1FFFFFFFFF
A-6	ALQ165	UNC2	900	3	2	1	1FFFFFFFFF

Figure 4. Sample of SPJ data in SPJ_880129.DAT file.

The data in Figure 4 is described by column as follows: column (1), aircraft type; column (2), jammer designation; column (3), weapon system the SPJ is effective against; column (4), altitude (in ft) to which the effectiveness applies; columns (5 to 8), the jamming effectiveness. The characters following the leading digit in column 8 are intelligence data specifiers used in the determination of the SPJ effectiveness against the specified weapon. The effectiveness against a weapon system is set by the numbers located in columns 5 through 8 of the data file shown in Figure 4. Table 5 shows the relation of SPJ effectiveness number to the users yes or no answers to IMOM SPJ options when selecting SPJ for an EOB.

The two options are: (1) if chaff is used by the aircraft carrying the SPJ; (2) if optical tracking methods are utilized by the radar system. Table 5 shows the combination of chaff

and optics that determine the column of data in Figure 4 IMOM will read the SPJ effectiveness to be displayed. The combination of YY, YN, NY, and NN in Table 5 correspond to Figure 4 columns 5 through 8.

TABLE 5	
SPJ OPTION SELECTIONS	
CHAFF	OPTICS
N	N
N	Y
Y	N
Y	Y

The SPJ jammer effectiveness is qualified as shown in Table 6. The effectiveness of the SPJ against a particular radar is currently not a value calculated by the IMOM model. The effectiveness is a predetermined level obtained from intelligence sources and qualified as either a 1, 2, or 3, with the corresponding effectiveness as shown in Table 6.

TABLE 6		
SPJ EFFECTIVENESS		
NUMBER	EFFECTIVENESS	RINGS COLOR
1	NONE	RED
2	35-70%	YELLOW
3	70-100%	GRAY

For this thesis, the SPJ_880129.DAT SPJ data file was edited using the Unix "vi" editor. Data was added in the

exact format as existing lines of data in the file. A more efficient mode of SPJ file modifications would be an executable program that prompts the user for the required data and updates the existing SPJ_880129.DAT file accordingly. This program could be used to delete current SPJ data, add new SPJ data, and display all current SPJ data. The program could be written in FORTRAN or C programming languages for the SUN microsystems workstation and located in the same directory as IMOM "run_infiles program". The program run_infiles is executed by the user to enter IMOM radar and jammer parameters. This program could be written as part of a future IMOM thesis.

Another example of future IMOM thesis work could be to develop a subroutine that would do the actual calculation of SPJ effectiveness against a particular radar by utilizing both the radar and jammer parameters entered in IMOM. In this way, jamming effectiveness could truly be a function of jammer parameters, SPJ aircraft range and aircraft heading as opposed to simply a qualitative number. The calculated effectiveness would still be based on the intelligence sources that define the SPJ effectiveness.

3. SOJ

The SOJ effectiveness is calculated by the IMOM model utilizing radar and jammer parameters, unlike the SPJ where a qualitative number specifies SPJ effectiveness. The SOJ effectiveness is calculated by the IMOM model for EW, HF, TA,

TT, and FC radars in any given order of battle. Table 7 shows the RINGS display color for effective jamming. IMOM calculates SOJ effectiveness on the basis of jammer position, heading, antenna pointing direction, beamwidth and polarization relative to the position of the radar mainlobe, sidelobes and backlobes. SOJ effectiveness for these situations is estimated from equations 18, 19, and 20 respectively. An example of SOJ effectiveness versus a EW radar is shown in Figure 5. The magenta triangle symbol is the SOJ aircraft.

TABLE 7

SOJ EFFECTIVENESS

RADAR	EFFECTIVE	COLOR
EW, HF, TA	NO	LIGHT BLUE
EW, HF, TA	YES	GREEN
TT, FC	YES	MAROON

The SOJ effectiveness is evaluated under three sets of conditions: (1) SOJ in the mainlobe if the SOJ position is in both the elevation and horizontal beamwidth of the victim radar as defined by IMOM, (2) SOJ in the sidelobe if the SOJ position is in the radar elevation beamwidth and one of the sidelobe azimuth beamwidths, and (3) SOJ in the radar backlobe when the SOJ position is not in the elevation beamwidth, or is in the elevation beamwidth and one backlobe beamwidth. These conditions determine which of equations 18, 19, or 20 are used to calculate the SOJ effectiveness.

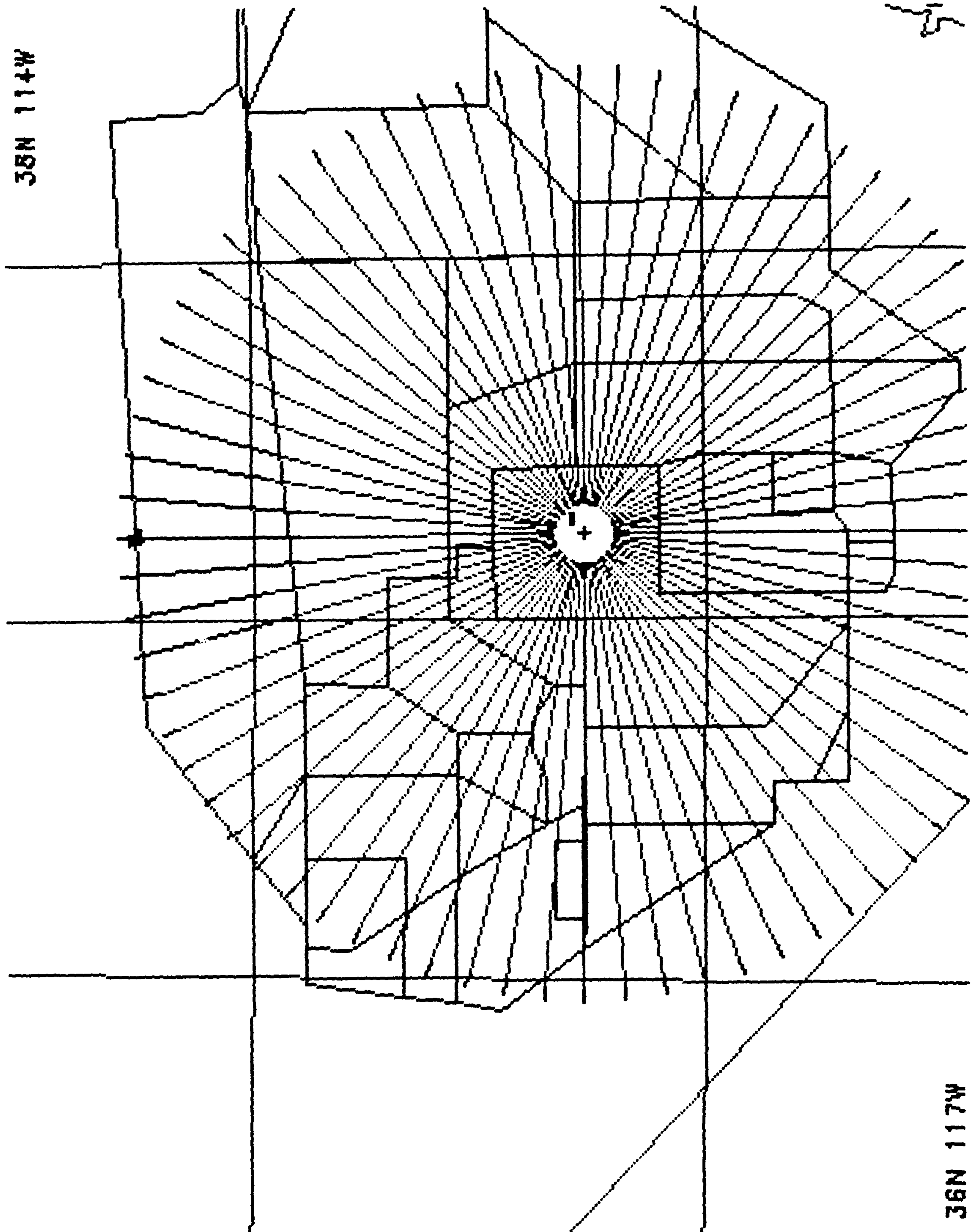

Figure 5. SOJ effectiveness versus EW radar.

The EW, HF and TA radar reduced detection range due to SOJ is displayed in green on the RINGS radials. Figure 5 showed the jamming effects of SOJ on an EW radar. If the SOJ is in a position to affect all lobes of the radar, the RINGS display clearly shows in green the where the ML, SL and BL detection are reduced. IMOM assumes the HF radar main beam is pointed at the SOJ aircraft when displaying the RINGS ML effects of the SOJ. For SL and BL effectiveness, the SOJ is assumed to be pointing at the radar for all remaining radials. The affected weapon range reduction is displayed in magenta for FC and TT radars.

The IMOM SOJ parameters and the data files where they are stored are covered in the following paragraphs. The general procedure for creating a jammer is also outlined.

Each jammer is given a jammer designation with a maximum of six characters in the form ALQ??? (i.e., ALQ100). The jammer file created is stored in the file ALQ???.JAM in the HOME/imom/ data/imom/imom_imom directory. The jammer must be assigned stations where the jammer oscillators will be loaded. A maximum of 10 stations per jammer is possible. An antenna direction and beamwidth is specified for each station. In this way, an SOJ with any azimuthal coverage up to 360 degrees can be created.

In order for SOJ to affect radars, oscillators must be loaded into specified jammer stations. A maximum of 4 oscillators per station is possible. The oscillators provide

the RF frequency coverage of the jammer. Each oscillator consists of a jamming technique, center frequency, and spot width. In order for an oscillator to be added to a station, and for IMOM to be fully programmed, a receive and transmit band must exist with the desired jammer parameters. The receive and transmit band data files contain the jammer operating parameters.

The SOJ operating band parameters are stored in the files RXBAND.DAT and TXBAND.DAT. RXBAND.DAT contains the jammer receiver characteristics and TXBAND.DAT contains the jammer transmitter characteristics. IMOM uses the data from these files in the jamming equations. The jammer data is entered following the menu prompts when "run_infiles" is typed on the keyboard at the UNIX operating system prompt. Figure 6 shows an example of the RXBAND.DAT file and Figure 7 shows an example of the TXBAND.DAT file.

BAND	MIN. FREQ.	MAX. FREQ.	L_{jr}	J_{MDS}	G_{jr}
BAND2	900.	3000.	3.0	-120.0	3.0
BAND3	2950.	6500.	3.0	-120.0	2.0
BAND4	6300.	12600.	2.0	-120.0	2.0
BAND5	11000.	18000.	3.0	-120.0	7.0
BAND8	2000.	13000.	3.0	-90.0	10.0
BAND10	2000.	14000.	3.0	-60.0	10.0

Figure 6. Sample RXBAND.DAT file.

BAND	MIN. FREQ.	MAX. FREQ.	ERP	P_j	L_{jt}	G_{jt}	ANTENNA BW_j	POL.
BAND1	300.	1030.	1000.0	1000.0	2.0	2.0	360	SLR
BAND2	980.	3020.	3639.4	2000.0	1.8	4.4	75	SLL
BAND3	3010.	6500.	5277.4	2200.0	1.2	5.0	80	RHC
BAND4	6450.	12880.	4062.1	1900.0	1.3	4.6	70	LHC
BAND5	9000.	18000.	501.2	100.0	3.0	10.0	26	VER
BAND8	2000.	13000.	501.2	100.0	3.0	15.0	60	VER
BAND10	2000.	14000.	15848.9	1000.0	3.0	15.0	60	VER

Figure 7. Sample TXBAND.DAT file.

Figure 8 shows the "run_infiles" display of a jammer. This listing summarizes a jammer by displaying the stations loaded (STN #), the corresponding receive and transmit bands (BAND), frequency coverage of the bands (FREQ RANGE (MHz)), jammer ERP (kW), station antenna beamwidth (BMW), station antenna pointing direction relative to nose of aircraft (AZM), station antenna polarization (POL), and number of oscillators loaded per station. Each oscillator is specified by a jamming technique, center frequency and spot width.

STN #	BAND	FREQ. RANGE (MHz)	AVR ERP (kW)	BMW (DEG)	AZM (DEG)	POL	OSCL LOADED
1	BAND1	300.-1000.	1.0	360	0	VER	4
2	BAND1	2000.-12000.	2.2	30	0	HOR	2
3	BAND1	2000.-12000.	4.5	60	0	RHC	3

Figure 8. Jammer summary displayed by "run_infiles."

The use of jamming techniques in IMOM consist of technique names and corresponding J/S ratios specified in the

radar files. The effectiveness of a particular jamming technique is defined by the J/S assigned to the technique in each radar file. The jamming techniques are listed in the file JAMMOD.DAT in the HOME/imom/data/imom/imom_imom directory. Figure 9 shows a sample of a JAMMOD.DAT file.

```
                 __ Noise
                |__ Time Dependent
                || __ # of oscillators
TECHNIQUE       |||

NOISE           Y Y 4
CONFUSION       Y N 4
DECEPTION       N Y 1
RGS             Y Y 4
```

Figure 9. Sample of JAMMOD.DAT file.

The JAMMOD.DAT file includes the jamming technique name, if it is a noise technique, if it is a time dependent technique, and the number of oscillators per station that the technique can use. This is the data file accessed by IMOM in order to select the jamming technique associated with a particular jammer oscillator. If multiple oscillators provide the same technique, IMOM adds the jamming power accordingly. In addition, in order for a jamming technique to be effective against a particular radar, the technique and corresponding J/S ratio must be entered in the radar *ELNOT*.RAD file. This is how a particular jamming technique is determined effective against a radar. The radar burnthrough range is calculated from the J/S for each technique. If multiple techniques are

effective against a radar, the minimum burnthrough range is used by IMOM RINGS display.

4. Multiple SOJ

Multiple SOJ aircraft can be modelled by IMOM. The RINGS display for a radar will show the SOJ effectiveness assuming the radar beam is pointed at each SOJ. The RINGS display for a radar affected by multiple SOJ aircraft will have a mainlobe reduction in detection range toward each SOJ. Figure 10 shows the jamming effectiveness from two SOJ aircraft against an EW radar, one to the north and one to the east. The ML and SL jamming effectiveness from each SOJ can be seen in the green portion of the radials.

5. SOJ and SPJ

Both SOJ and SPJ can be specified in an order of battle. Selecting SPJ for an order of battle automatically affects the RINGS display for all FC and TT radars when RUN RINGS is selected. The RINGS radials are colored according to the SPJ effectiveness specified for the associated weapon systems described earlier. The SOJ effectiveness is evaluated for each radar in the order of battle according to the description given above. Figure 11 shows the effects of both an SPJ and an SOJ on TA and TT radars in the EOB.

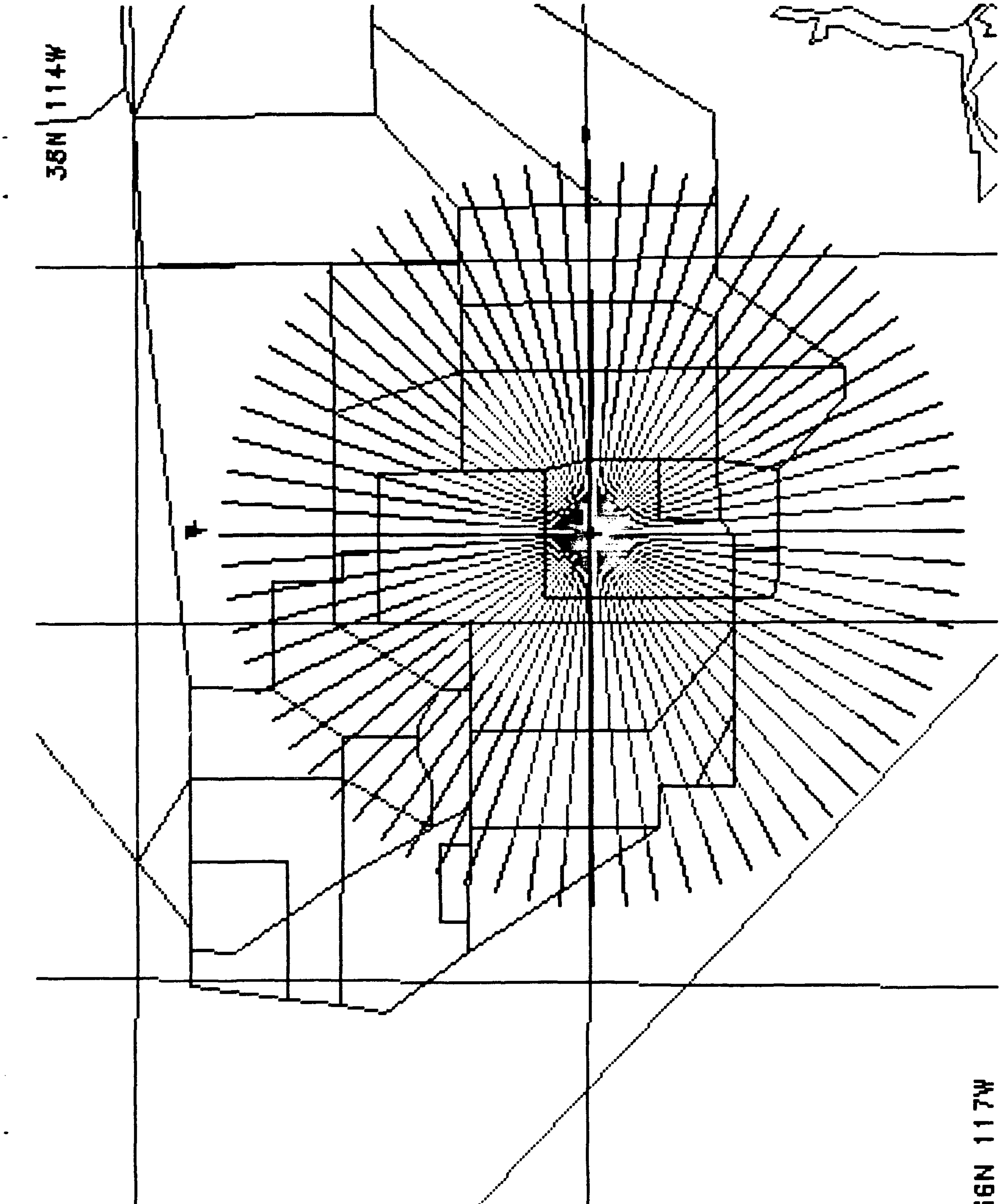

Figure 10. Two SOJ aircraft jamming an HF radar.

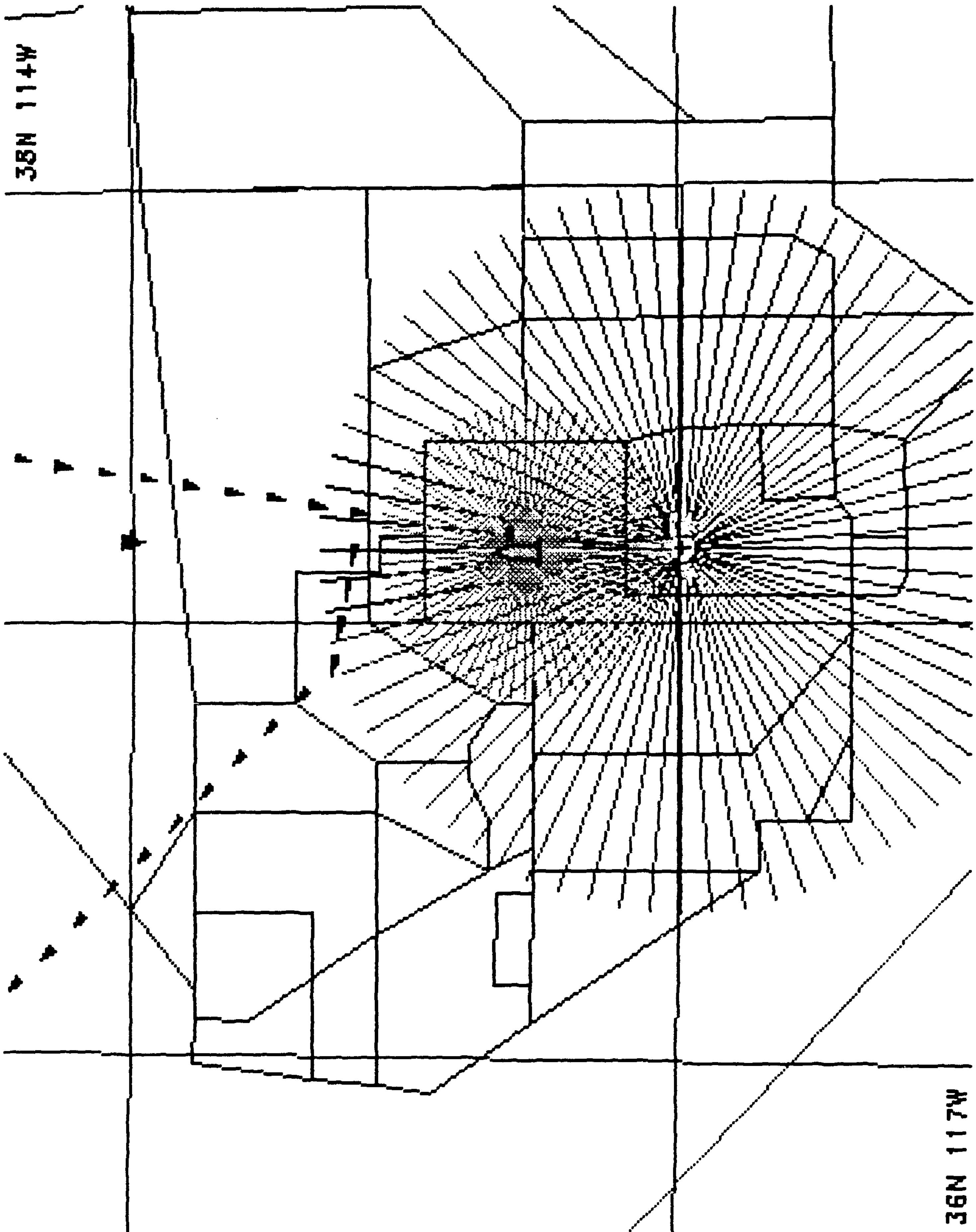

Figure 11. SOJ and SPJ effects on TA and TT radars.

6. Airborne Radars

An airborne radar can also be modelled by IMOM. The RINGS display calculates the radar coverage the same as for a ground based radar. The difference in the RINGS display between ground and airborne radars is that the current IMOM model does not evaluate any jammer effectiveness against an airborne radar. Therefore, when airborne radars are entered into the EOB, the radar coverage is for display purposes only. Figure 12 shows an example of two fighter aircraft FC radars and an AWACS EW radar aircraft.

This lack of jamming evaluation for airborne radars presents a topic for a future IMOM thesis. Research and analysis for airborne radars would produce a module addition to the IMOM model that would give results simulating jamming like that of the ground based radars. A student might add a module to the existing IMOM model to perform jammer effectiveness versus airborne radars in the EOB. The effectiveness could be evaluated based on the radar and jammer parameters, antenna pointing directions, and position of the jammers relative to the radars. With the addition of full airborne radar effectiveness, realistic air-to-air jamming scenarios may be modelled.

7. Radar Beams Display

IMOM also has a "BEAM DISPLAY" function, where a particular radar beam, or multiple beams, is displayed

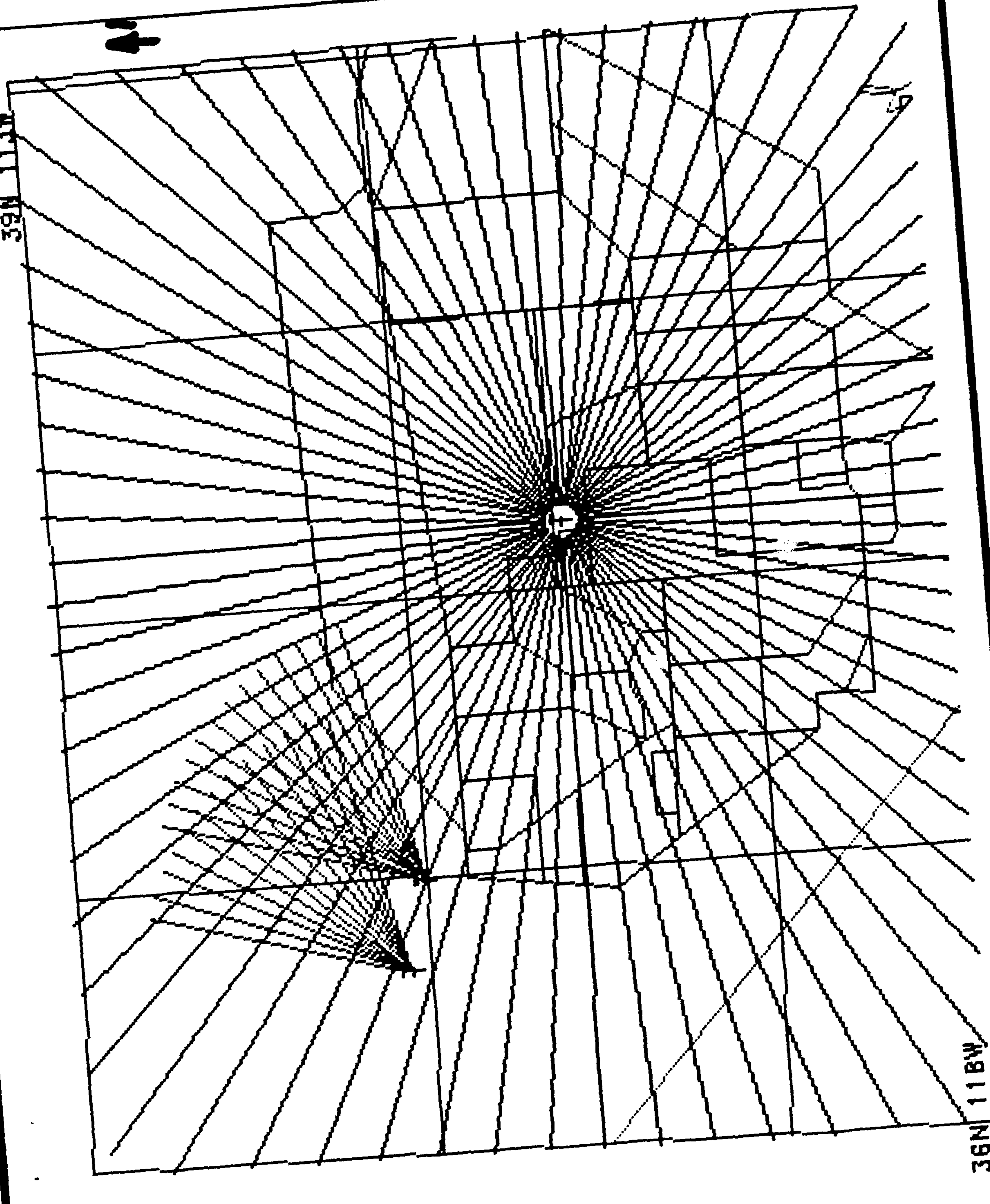

Figure 12. Airborne FC and EW radars.

versus range and altitude. The altitude of a target aircraft, or SOJ aircraft, is entered as well as the distance from the radar. The BEAMS DISPLAY then shows a vertical slice along a particular azimuth for this aircraft, relative the radars beam or beams. Figure 13 shows an example of a radar beams display.

8. Frequency Coverage

The total EOB frequency allocations for radars, jammers, and both can be displayed. An example of the frequency display is shown in Figure 14. The frequencies of the radar beams are spikes and color coded for the type of radar. Jammer frequencies, corresponding to jammer oscillator loading, appear as half height spikes. The frequency scale is listed along the bottom edge of the display window.

This screen provides a display of which radar frequencies are affected by jamming. The unaffected radar frequencies are clearly visible by the lack of a jamming cover spike. By selecting only a single or certain radars, the display will show a wide spike for the jamming signal, where the width corresponds to the spot bandwidth of the jammer at that frequency.

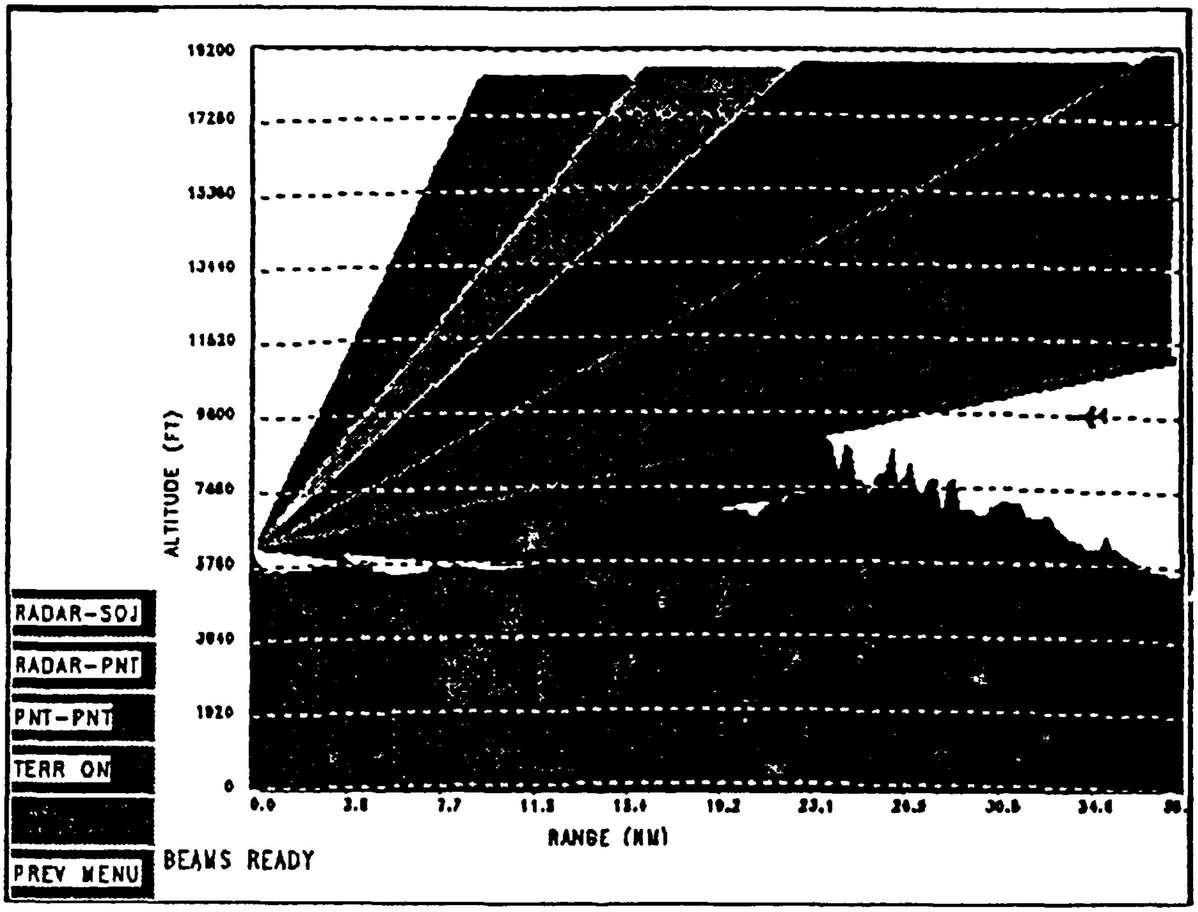

Figure 13. Radar beams display. [from Ref. 4]

Text files are also available summarizing the radars and jammers and their associated operating frequencies. These are a text listing of the graphics frequency display mentioned above. An example of the text listing for the radars is shown in Figure 15 and for the jammers in Figure 16.

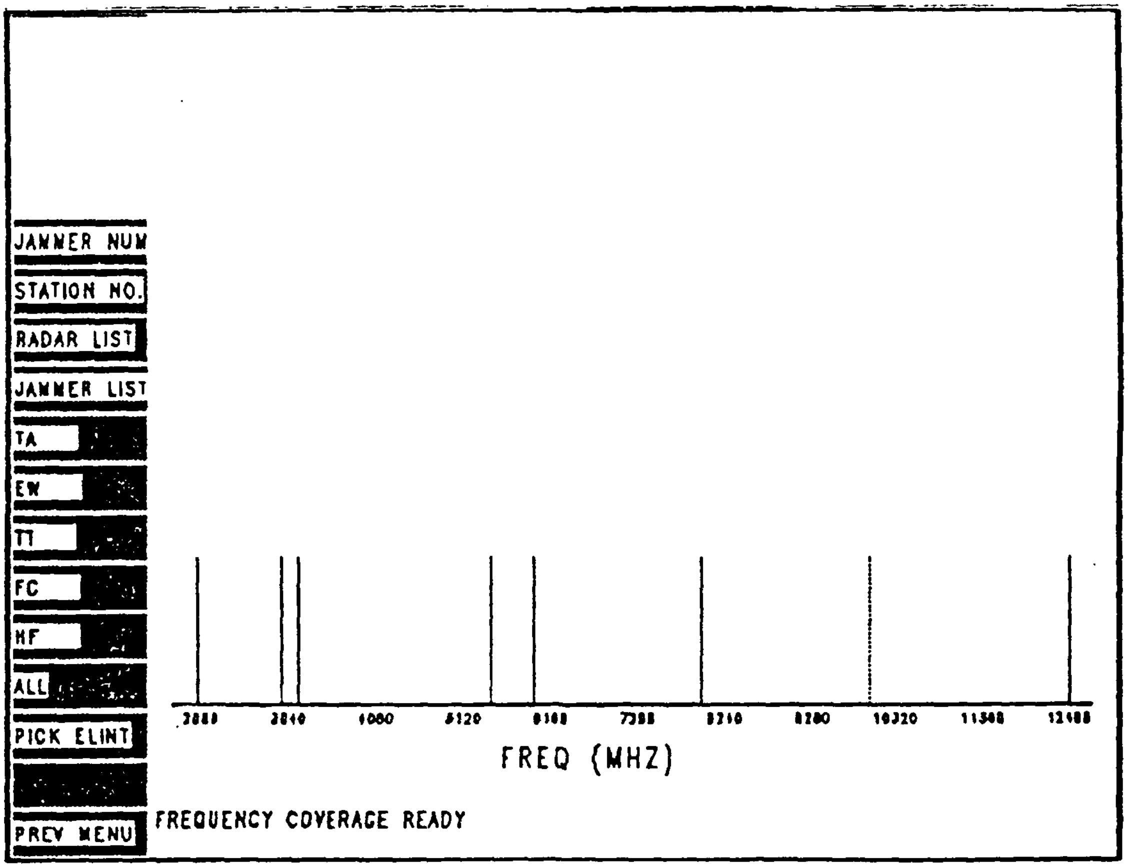

Figure 14. Frequency coverage display window. [from Ref. 4]

EOB FREQUENCIES

ELINT	NATO DESIGNATION	FUNCTION	FREQ (MHZ)	WEAPON
B222U	NEW JERSEY	TT	5500.	UNC1
B333U	TEXAS	EW	3000. 3000. 3000. 3200. 3200.	
D333U	MEXICO	TT	6000.	UNC4
G333U	MICHIGAN	TT	12400.	UNC2
V444U	MARYLAND	TA	2000.	

Figure 15. Frequency coverage text window for radars. [from Ref. 4]

JAMMER FREQUENCIES

NUMBER	NAME	STATION	OSCILLATOR	CENTER FREQ (MHZ)	SPOT (MHZ)
1	UNCLSEUR	1	1	850	1.0
			2	850	1.0
		2	1	3000	1.0
			2	2000	1.0
		3	1	6000	1.0
			2	5500	1.0
		4	1	3200	10.0
		5	1	7500	5.0
			2	12400	5.0
		6	1	7920	2.0
			2	6650	20.0
		7	1	8000	10.0
			2	10000	20.0
		8	1	9250	10.0

Figure 16. Frequency coverage text window for jammers. [from Ref. 4]

9. JAMMING ON/OFF Toggle

The JAMMING ON/OFF toggle provides another tool to view SOJ effectiveness. This toggle has the effect of turning off the portion of a radars radials that are degraded by jamming (green portion). This creates a clear area on the screen where radar detection of any aircraft in this area has been prevented. Figure 10 showed a radar RINGS display with jamming on. The difference between Figure 10 and a display with JAMMING OFF is that the green portion of the radar radials in Figure 10 are turned off. This means that a zone normally within the detection capability of a radar is now clear because of jamming.

10. ROUTE

The ROUTE feature allows the student to view detection capabilities of all radars in a geographical area, taking into account the EOB for a specified aircraft flight path. This helps the student understand the importance of radar placement as it effects ingressing aircraft detection. Simple examples of the IMOM ROUTE feature already appeared in Figures 3 and 11. The IMOM ROUTE feature provides a user the capability to create a flight path for the SPJ aircraft in the EOB, view which radars detect the aircraft, and the probability of the radar harming the aircraft along the flight path. The user enters the desired flight path with the computer mouse and sets the position increments where IMOM will perform analysis.

After the route is entered, the "RTE ANAL" feature is selected.

IMOM produces triangle symbols along the flight path at the specified position increments. The positions are numbered sequentially from the start point to the end point. Each position is color coded to match the most harmful radar detection capability in the EOB. Table 8 lists the ROUTE triangle color codes. A key point to note here is that the ROUTE positions are color coded whether or not the RINGS display is enabled. In this way the route can be viewed in an uncluttered display. An example of a ROUTE display with RINGS on is shown in Figure 17. The same ROUTE with rings off is shown in Figure 18. Figure 19 is a zoomed view of ROUTE positions 14-17 allowing the user to view radar detection at a single position. For example, position 15 is within detection range of 3 radars, represented by the in blue, red and gray RINGS radials.

TABLE 8	
ROUTE TRIANGLE COLOR CODING	
LIGHT BLUE	EW, TA or HF detection
GREEN	Screened by SOJ against EW, TA or HF
RED	Within lethal envelope of TT or FC
MAGENTA	SOJ preventing TT or FC lock-on
YELLOW	SPJ degrading TT or FC lock-on
GRAY	SPJ degrading TT or FC lock-on
WHITE	Out of range of any radar
DARK BLUE	Terrain masked from all threats

In addition, a summary file is created for the route containing radar detection at each position. The data presented is helpful in planning SOJ placement in order to counter high priority TT and FC radars that can detect the aircraft. Figure 20 shows a sample from the route summary at position 15.

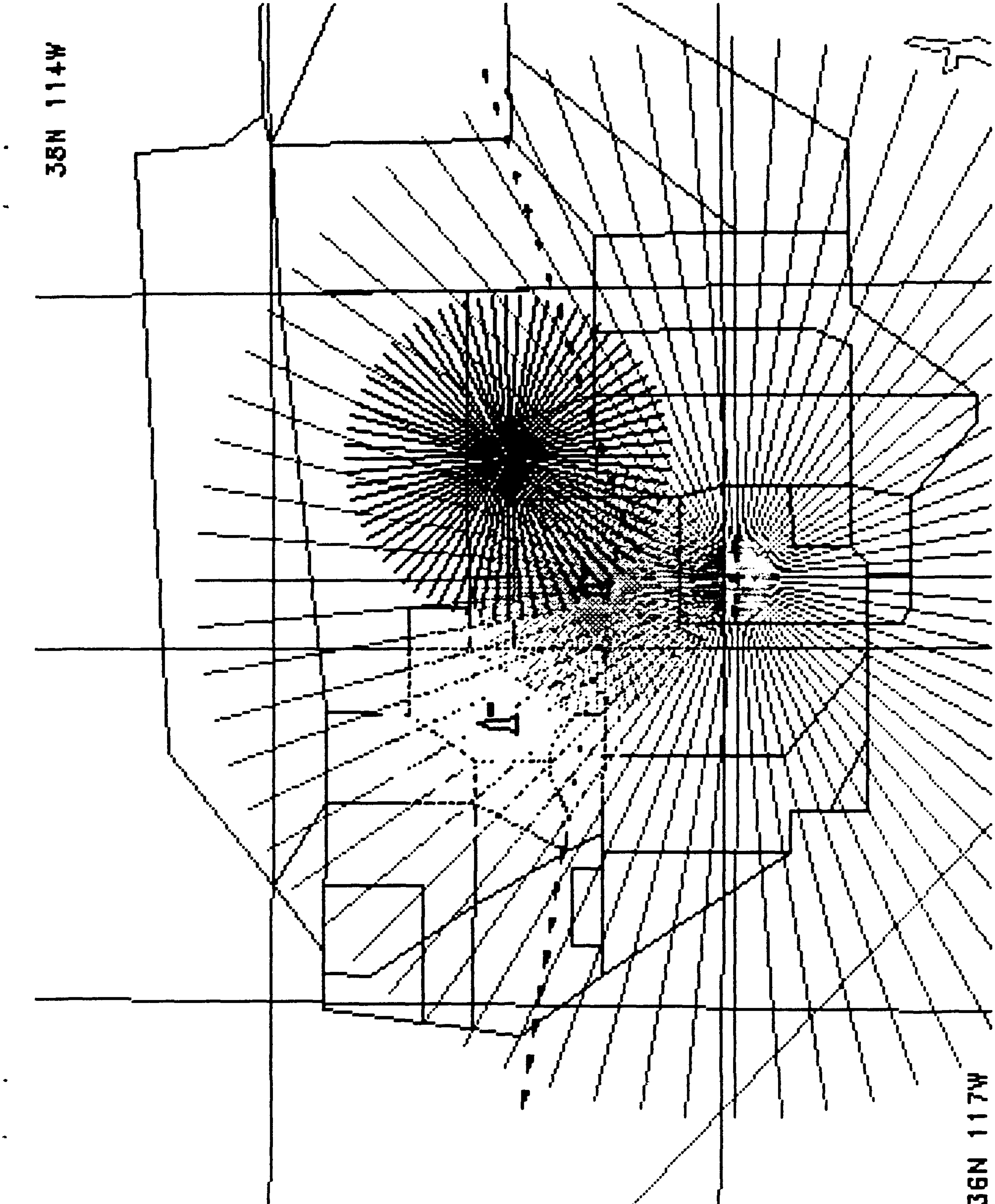

Figure 17. ROUTE with RINGS turned on.

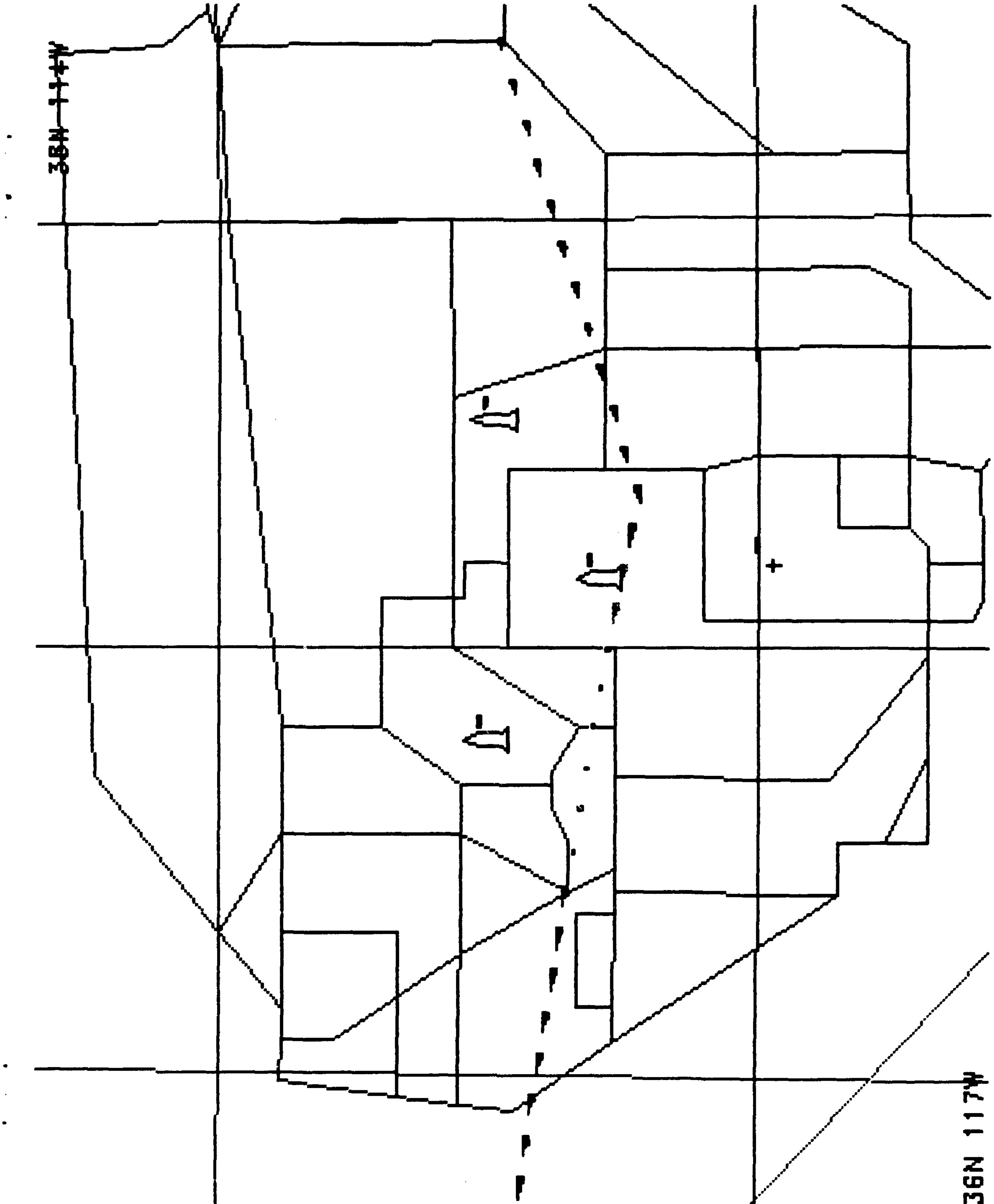

Figure 18. ROUTE with RINGS turned off.

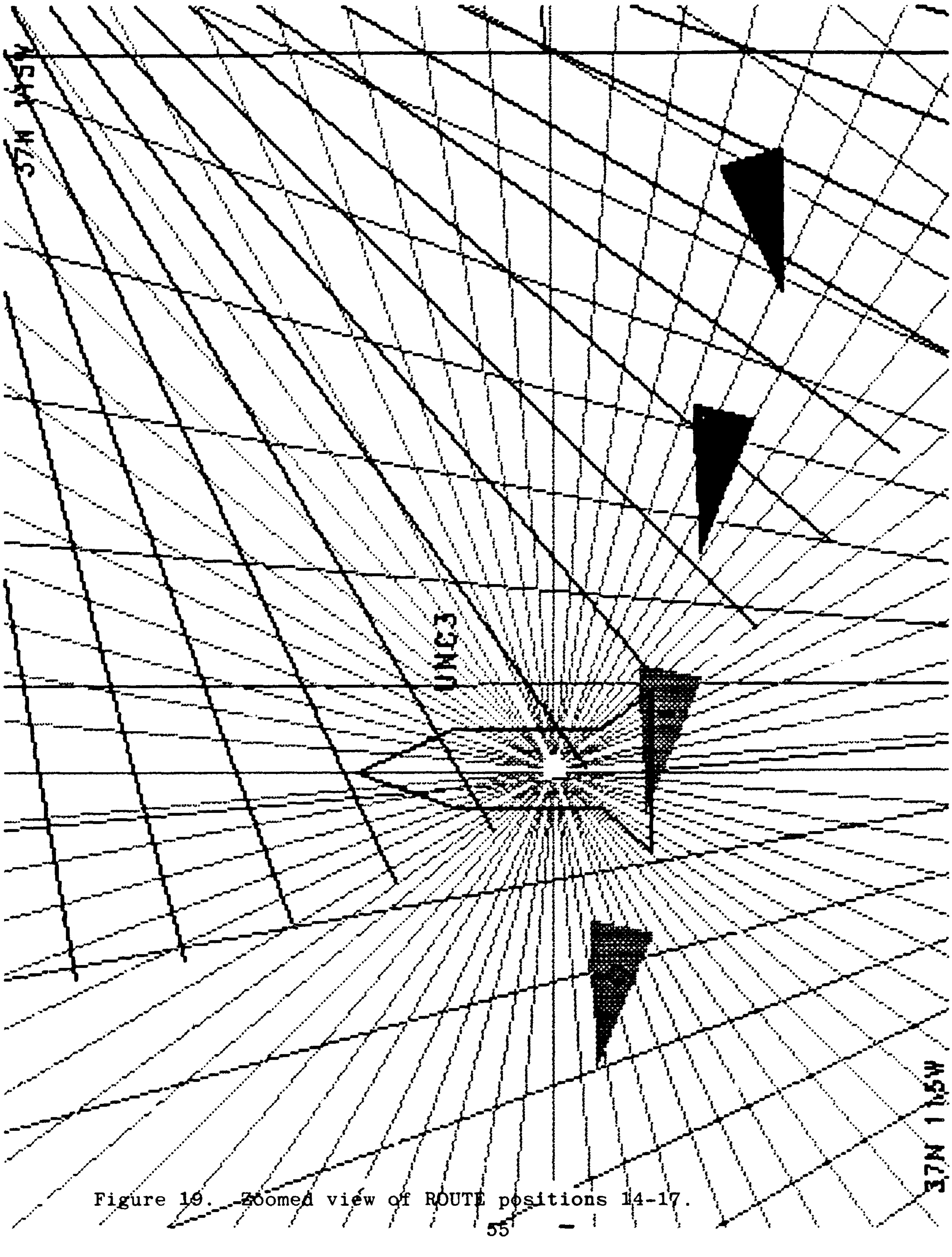

Figure 19. Zoomed view of ROUTE positions 14-17.

```
                 AIRCRAFT ROUTE POSITION NUMBER 15
 AIRCRAFT TRUE COURSE IS  281 DEGREES
 AIRCRAFT ALTITUDE IS    5000 FEET AGL
 AIRCRAFT POSITION IS LAT: 371413N LON: 1154341W

        THREAT NAME         TYPE   CLOCK    RANGE (NM)  TERRAIN MASKING ALT.
ELNOT NATO NAME        WEAPON      POSITION             FEET AGL    FEET MSL
---------------------------------------------------------------------------
W222U DELAWARE         UNC3   TT     1         6           0           0
  AT 371655N 1155010W   URADAR      2
  IOC=MM  BE#=          SITE NAME=                       /TOB/
B222U NEW JERSEY       UNC1   TT     4         19         120         120
  AT 372843N 1152759W   URADAR      5
  IOC=MM  BE#=          SITE NAME=                       /MOB/
RAD04 THESIS                  HF     9         16          57          57
  AT 365820N 1154822W   URADAR      6
  IOC=ME  BE#=          SITE NAME=                       /EOB/
```

Figure 20. Sample at position 15 from ROUTE summary file.

To summarize, the relevant IMOM display features for this thesis are related to the RINGS, FREQ COVRG, and BEAM DISPLY features described in detail above. The RINGS, FREQ COVRG, and BEAM DISPLY attributes of IMOM provide a means to display radar detection and jammer effectiveness characteristics. These characteristics can then be compared to the theoretical data calculations. The ROUTE feature displays detection characteristics at the specified position increments from each of the radars in the EOB.

V. IMOM UTILIZATION

IMOM will be utilized to display radar and jamming principles presented in NPS coursework. Radar and jamming equations are derived in class, and numerical calculations are carried out in an effort to describe operational capabilities. This thesis carries the material presented in radar and EW courses and laboratories one step further. The equations are used to plot radar and jammer characteristics for a given set of radar and jammer parameters. These same parameters are entered into IMOM and the results observed on the computer generated graphics. The applicable IMOM color graphics displays were presented in the information presented by IMOM section in Chapter IV.

A. GRAPHICAL DISPLAY OF THEORY

Chapter III presents the radar and jammer equations related to the IMOM model. Chapter IV presents the IMOM display characteristics that show radar coverage and jamming effectiveness relative to the user defined EOB. This chapter presents the graphical display of the theoretical calculations to be used to validate by the IMOM display of the EOB.

The computer program to display the radar and jammer characteristics is written for a personal computer using MATLAB. The program, rdrrng.m, source code listing is included in Appendix A. The objective of the MATLAB program

is to plot the radar and jamming data resulting from using the equations. The calculated radar and jammer characteristics are plotted versus range in order to provide a means to confirm the values achieved by IMOM.

The radar and jamming characteristics calculated by the equations presented in Chapter III are listed in Table 9. Table 9 is important because it presents the characteristics used by the IMOM model to generate the RINGS display showing radar and jammer interaction. The range calculations provide detection limitations for the radars and the J/S calculations provide the basis for SOJ effectiveness evaluation.

The MATLAB program operates as follows. The user is prompted to input radar data or recall an existing radar data file. Figure 21 shows a radar data file created by the rdrrng.m program. The name of the radar data file is given the same name as the radar ELNOT entered in IMOM and is in the form *ELNOT*.par. The radar data is also stored in MATLAB data format in a *ELNOT*.mat for the radar recall feature of the program.

After the radar file is entered, the user is prompted for the jammer parameters. The user can recall or create a jammer file. Figure 22 shows a jammer data file created by the rdrrng.m program. The name of the jammer data file is given the same name as the jammer designation entered in IMOM and is in the form *ALQ???*.par. The jammer data is also stored in

MATLAB data format in a file *ALQ???*.mat for the jammer recall feature of the program.

TABLE 9	
CALCULATED CHARACTERISTICS	
R_{max}	Maximum detection range
R_h	Horizon limited range
S	Target signal return
J	Noise SPJ signal return
J/S	Noise SOJ J/S ratio
J_{cg}	Deception constant gain
J_{cp}	Deception constant power
R_{sat}	Jammer saturation range
J_{cg}/S	Deception constant gain J/S
J_{cp}/S	Deception constant power J/S
J_{Ml}	Noise SOJ radar mainlobe
J_{Sl}	Noise SOJ radar sidelobe
J_{Bl}	Noise SOJ radar backlobe
J_{Ml}/S	SOJ mainlobe J/S
J_{Sl}/S	SOJ sidelobe J/S
J_{Bl}/S	SOJ backlobe J/S

```
RADAR: RAD03
Ant. Ht. = 10 m     32.8084 ft
Ppk = 1600 kW
Gt = 30 dB
Gr = 30 dB
f = 9.5 GHz
Br = 1000000 Hz
PW = 1e-06 s
Lr = 3 dB
Fn = 7 dB
I = 20 dB
S/N = 10 dB
Sidelobe dB down = 10 dB
Backlobe EL. dB down = 20 dB
Backlobe AZ. dB down = 20 dB
Ru = 400 km    215.983  nmi
Scope Range = 200 km   107.991 nmi
PRF = 375 Hz
Pav = 600 W
RCS = 10 sq m
Alt. = 5000 ft
```

Figure 21. Radar data file created by rdrrng.m (RAD03.par).

```
Jammer: ALQ800

Gjr = 10 dB
Ljr = 3 dB
Gja = 70 dB
Pj = 1000 W
Ljt = 3 dB
Gj = 15 dB
Bj = 10 MHz
MDS = -60 dBm
Rsoj = 112 km    60.4752 nmi
```

Figure 22. Jammer data file created by rdrrng.m (ALQ800.par).

The program then calculates the values listed in Table 9. The radar signal, jammer signal, and J/S values are calculated versus range from 0.1 to 1000 nmi. After all calculations are complete, the rdrrng.m program generates three plots displaying the data listed in Table 9. Figures 23-25 show the plots generated for the data given in Figures 21 and 22. The same data will be graphically displayed by IMOM in a two-dimensional color graphics display.

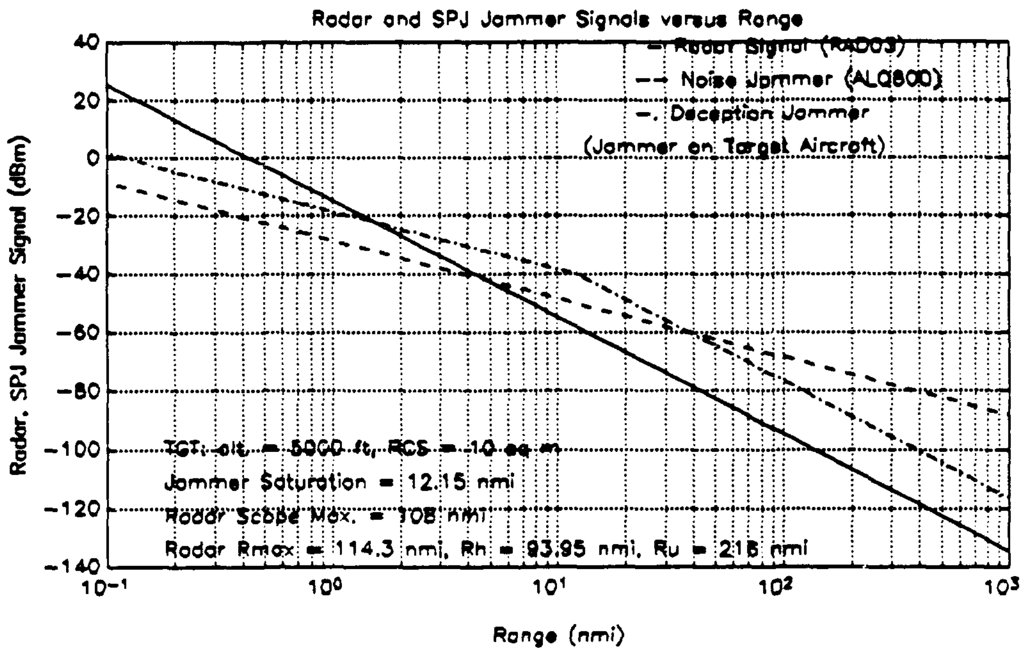

Figure 23. Radar signal return, noise SPJ and deception SPJ plot output by rdrrng.m.

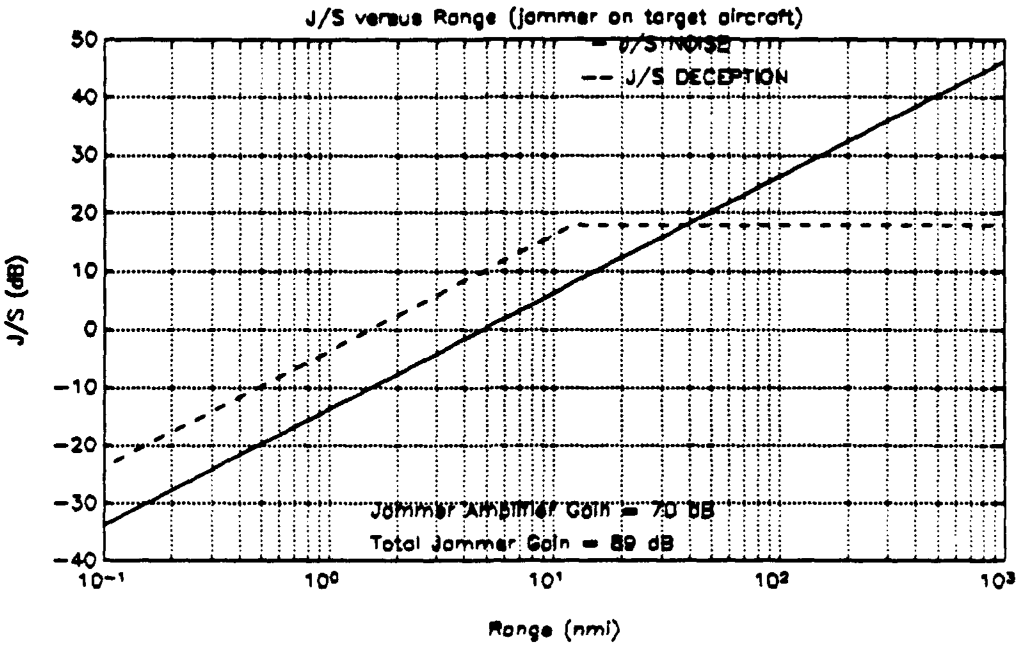

Figure 24. Noise and deception SPJ J/S plot output by rdrrng.m.

The data shown in the plots will be compared to the IMOM RINGS display as follows. The IMOM radar ELNOT file contains specific J/S values for the jamming techniques that are defined to be effective against the radar. These J/S values are the J/S levels required by the radar to obtain burnthrough against the SOJ. Therefore, the radar burnthrough range for each technique listed in the radar file, can be calculated from the rdrrng.m generated J/S plots. How this is done is described in the physical representation of theory section below.

The maximum detection range, R_{max}, horizon limited line of sight range, R_h, maximum scope range, and unambiguous range,

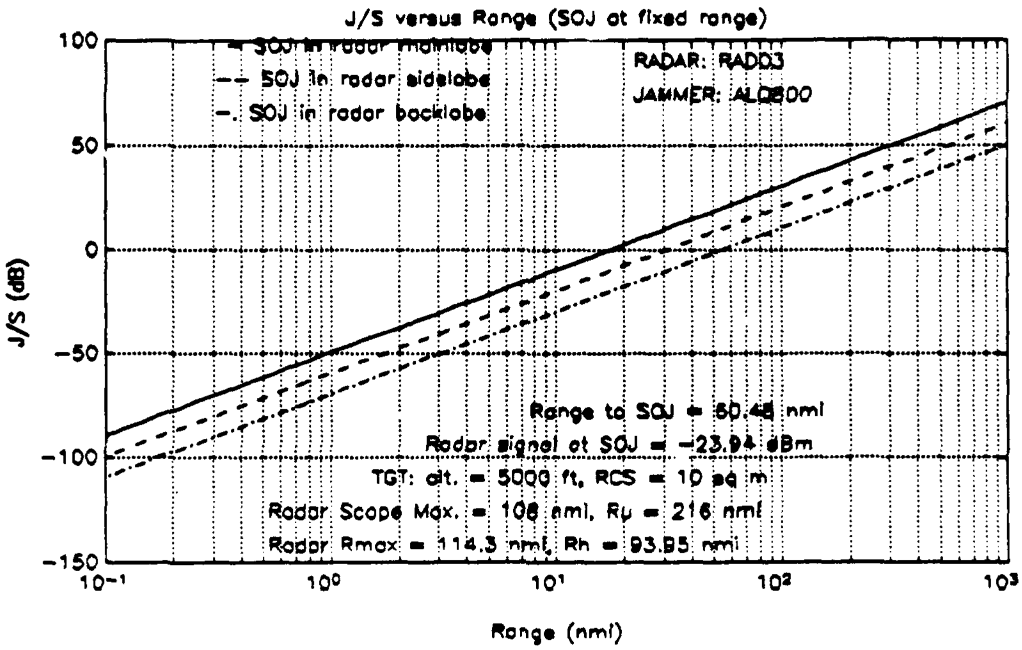

Figure 25. SOJ J/S plot output by rdrrng.m.

R_u, can also be read from the plots in Figures 23 and 25. These, along with terrain limited LOS, are used by IMOM to determine the radar maximum detection range, or RINGS radial length. Also shown in Figures 23 and 25 are the target RCS and altitude used in the calculations. The R_{max} and R_h values calculated match the IMOM display characteristics (R_{max} = 114.3 nmi, and R_h = 93.95). A specific example of these comparisons is provided in the radar exercises in Chapter VI.

The SPJ deception jammer saturation range, R_{sat} = 12.15 nmi, is also listed in Figure 23. The saturation range can also be read from Figures 23 and 24 at the point where the slope of the SPJ deception plot changes. This is the transition from constant gain to constant power output.

The radar burnthrough range can be read from Figure 23 or 24. The crossover point of the noise SPJ signal and the radar return signal is the radar burnthrough range assuming this occurs when the radar signal equals the jammer signal. If the radar had a specified J/S for SPJ noise jamming, the burnthrough range is read from Figure 24. The range is read from the graph at the given J/S.

The radar burnthrough range against SOJ noise jamming is calculated from Figure 25. Given the required J/S for radar burnthrough, the range can be read from the graph for SOJ mainlobe, sidelobe and backlobe jamming. For example, if J/S = 10 dB is given, burnthrough range in ML = 30 nmi, SL = 55 nmi, BL = 100 nmi.

B. PHYSICAL REPRESENTATION OF THEORY BY IMOM

Chapter IV described the IMOM display capabilities relating to the radar and jamming equations. The sections below describe the direct comparison of theoretical data plots to the IMOM displays.

1. Radar Characteristics

As discussed previously, IMOM RINGS displays the maximum radial length, or radar detection range, based on five criteria. The maximum radial length is taken as the minimum of one of the following; R_{max}, R_h, R_u, radar scope range, or terrain masking. For a weapon system, the target altitude is set and then the maximum detection range is selected from the THREATCAP.DAT file, in the HOME/imom/data/imom/elint

directory. Figure 26 shows one example where the RINGS radial maximum corresponds to the R_h given in Figure 25. In this case R_{max} is 114 nmi, but R_h is only 93.9 nmi. Terrain limited radials for the same radar are shown in Figure 27.

Figure 3 shows three TT radars with associated air-to-air missile weapon systems. The TT maximum radials are limited to the weapon envelope for a target at 5000 ft. altitude, even though the radar parameters match the parameters for the R_{max} radar radials displayed in Figure 1. A TA radar can be colocated with the TT in order to display the radar coverage provided by both radars (shown in Figure 2).

Figure 28 shows an example of airborne radars included in an EOB with ground radars. The figure shows two airborne fighter aircraft (northwest quadrant of plot) with their associated FC radars and an AWACS aircraft (located east of ground radars) with its associated EW radar along with the ground radars. The radials from these airborne radars are displayed using the R_{max} calculation for the given radar parameters, including antenna beamwidth coverage. The limited scan range of the fighter FC radars is clearly seen as well as the 360 degree coverage of the AWACS radar. Jamming is not evaluated for airborne radars as stated before.

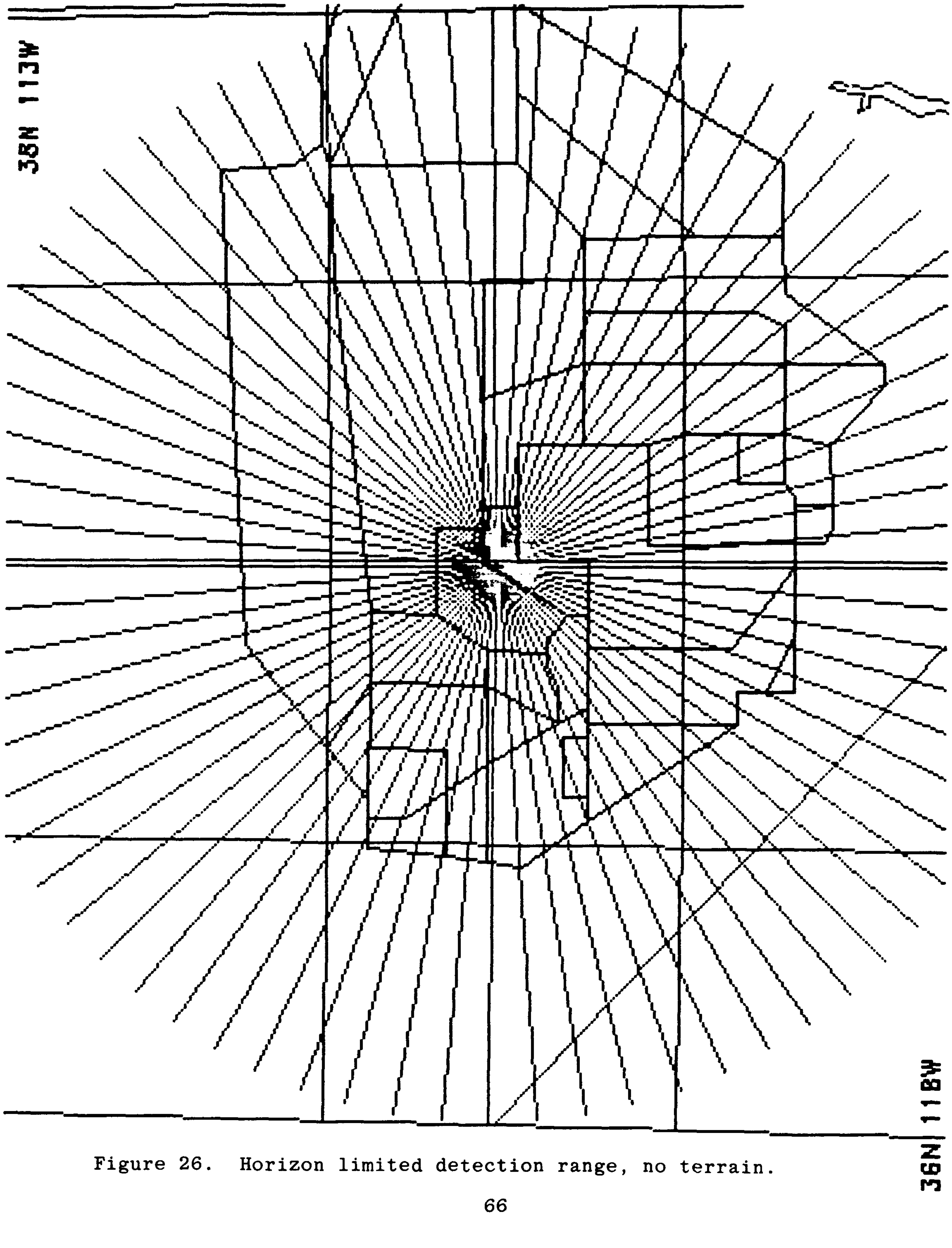

Figure 26. Horizon limited detection range, no terrain.

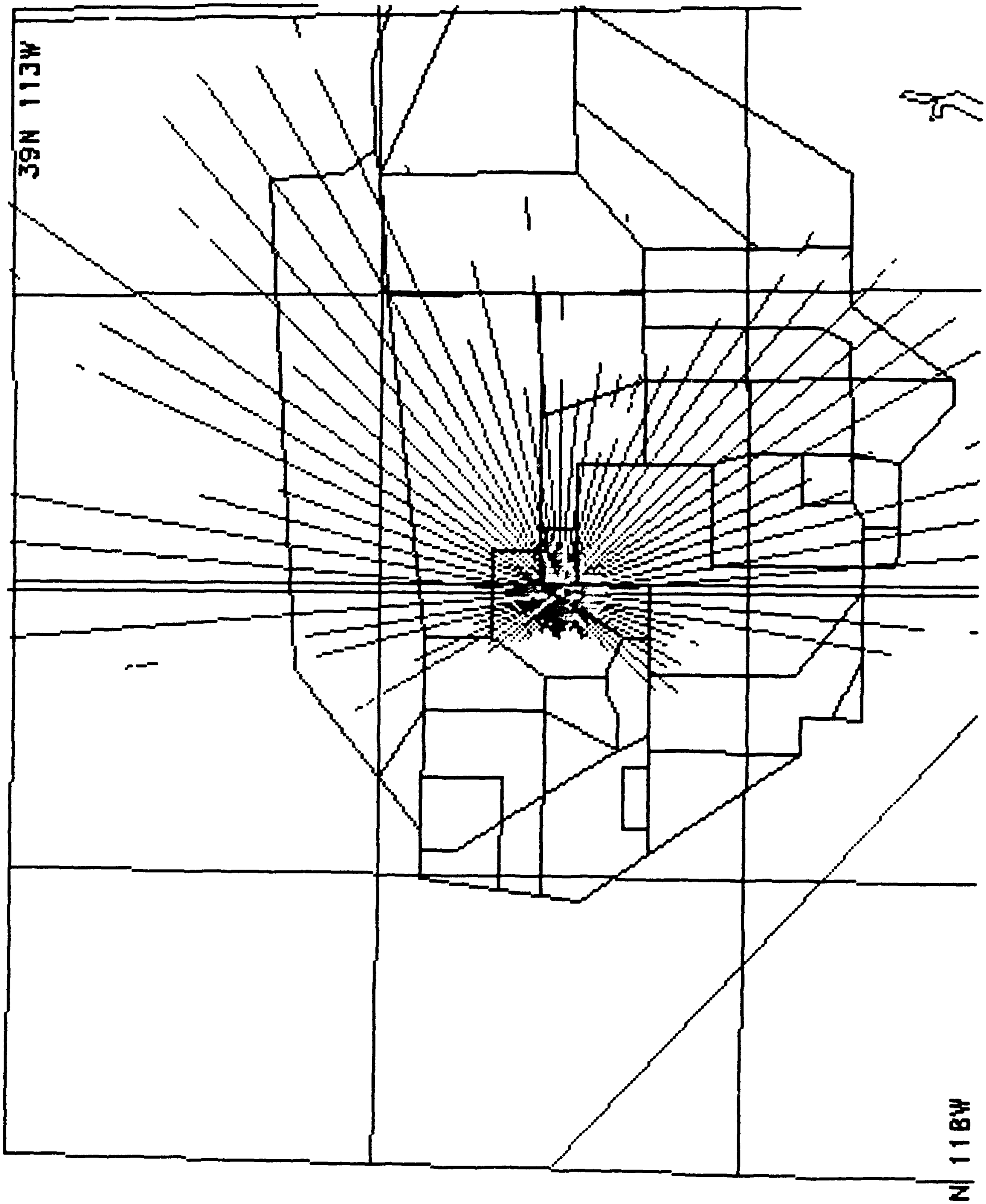

Figure 27. Terrain limited RINGS radials.

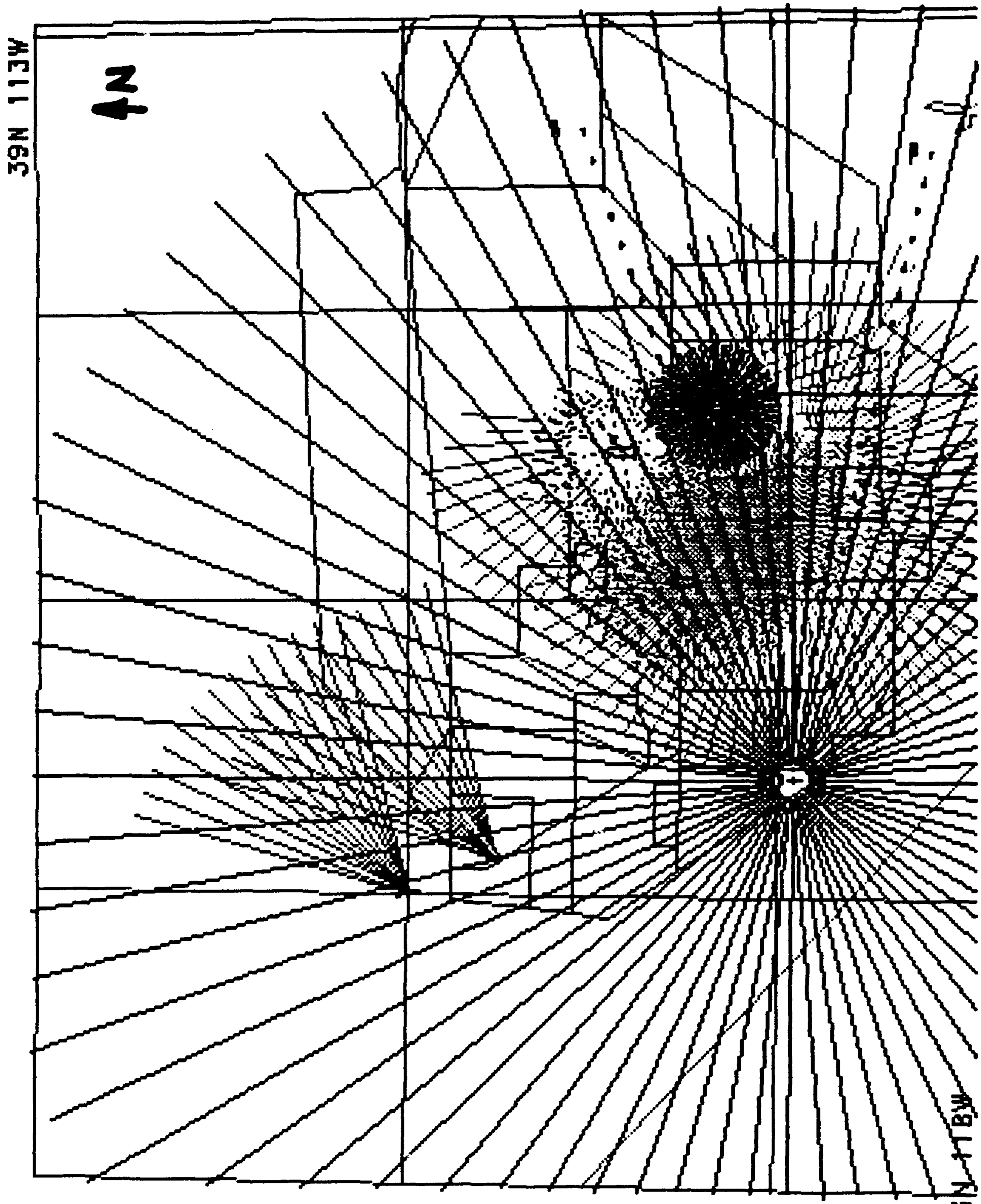

Figure 28. EOB with ground radars, airborne radars, SPJ and two SOJ aircraft.

2. Jamming Characteristics

IMOM SPJ effectiveness is not evaluated as it is for SOJ. The SPJ effectiveness is instead a qualitative value stored in the data file SPJ_880129.DAT, which is read by IMOM if SPJ is specified for a EOB. All TT and FC radars in the EOB are displayed according to the effectiveness specified in the SPJ_880129.DAT file. The rdrrgn.m generated SPJ signal and J/S plots are intended to show the theoretical calculation of SPJ jamming since they have no corresponding IMOM display attribute.

The SOJ display capabilities of IMOM present a color coded view of SOJ and radar interaction. SOJ effectiveness is evaluated against all radars in a EOB, whereas the SPJ is evaluated for only TT and FC radars. The IMOM RINGS display for SOJ is directly comparable with the rdrrng.m SOJ J/S data plots.

Comparison of the calculated SOJ effectiveness and RINGS display is described here. To read the calculated range for a specific J/S, the J/S value is read on the vertical axis. Refer to Figure 25 for an example of the SOJ J/S versus range. The intersection of this J/S level with the ML, SL and BL jamming signal lines are then projected down to the horizontal range axis. The ranges read at these points are the burnthrough ranges for the radar against ML, SL, and BL SOJ. These ranges will correspond to the lengths of the IMOM RINGS radials, where the color changes from blue to green. If

an SOJ is effective against a TT or FC radar the same jamming effectiveness can be read where the RINGS color changes from red, yellow, or gray to magenta.

The placement of SOJ aircraft is up to the IMOM user. The range from radar to SOJ will affect the SOJ effectiveness, as will the antenna direction and polarization of the SOJ. IMOM allows the user to specify an antenna direction with each station loaded in a jammer. This would physically require an antenna for each station specified for the jammer. The effect of changes in SOJ characteristics on an EOB can be observed. Effects of SOJ changes such as, placing the SOJ out of the radar beam coverage, antenna direction of certain stations, and jammer transmitter parameters can be observed.

VI. RADAR EXERCISES

This chapter presents specific examples of theoretical calculations and the corresponding IMOM program displays. The result is a physical presentation of radar principles.

A typical sequence of events a student might be expected to follow is outlined in Table 10. The student can perform the theoretical calculations manually using a calculator and plot the data with semilog paper, write a MATLAB program to calculate and plot, or run the rdrrng.m MATLAB program developed for this thesis. It would be up to the instructor to decide which method, or if all, would be utilized to derive the results.

The rdrrng.m MATLAB program was run to calculate the theoretical capabilities of the radar and jamming to be compared to the IMOM displays to be created. The specific radar parameters used in this example are shown in Figure 29, where Figure 29 is the RAD04.par file created by running the rdrrng.m program.

Appendix B shows all of the radar parameters entered into the IMOM model. Each block shown in the appendix is displayed in sequence when reviewing the radar parameters when "run_infiles" is executed.

TABLE 10	
RADAR ANALYSIS PROCEDURE	
STEP	DESCRIPTION
1	Given radar parameters.
2	Write own or use rdrrng.m MATLAB program to calculate and plot radar signal return versus range.
3	Calculate R_{max}.
4	Calculate R_h.
5	Calculate and plot noise SPJ signal at radar versus range.
6	Calculate R_{sat} for deception jammer.
7	Calculate and plot deception SPJ signal versus range.
8	Calculate and plot SOJ mainlobe jamming versus range.
9	Calculate and plot SOJ sidelobe jamming versus range.
10	Calculate and plot SOJ backlobe jamming versus range.
11	Given J/S, find radar burnthrough range for ML, SL and BL SOJ.
12	Given J/S, find radar burnthrough range versus noise SPJ.
13	Given J/S, find radar burnthrough range versus deception SPJ.

The specific jammer parameters used in this example are shown in Figure 30, where Figure 30 is the alq900.par file created by rdrrng.m. Figures 31-33 show the plots created by rdrrng.m utilizing the parameters from Figures 29 and 30.

Table 11 presents a summary of the sequence of actions to be followed, with important parameters used to create the

```
RADAR: RAD04
Ant. Ht. = 10 m    32.8084 ft
Ppk = 250 kW
Gt = 30 dB
Gr = 30 dB
f = 9.5 GHz
Br = 1000000 Hz
PW = 1e-06 s
Lr = 3 dB
Fn = 7 dB
I = 20 dB
S/N = 10 dB
Sidelobe dB down = 10 dB
Backlobe EL. dB down = 20 dB
Backlobe AZ. dB down = 20 dB
Ru = 400 km    215.983  nmi
Scope Range = 400 km   215.983 nmi
PRF = 375 Hz
Pav = 93.75 W
RCS = 10 sq m
Alt. = 5000 ft
```

Figure 29. Radar parameters (RAD04.par).

```
Jammer: ALQ900

Gjr = 10 dB
Ljr = 3 dB
Gja = 70 dB
Pj = 1000 W
Ljt = 3 dB
Gj = 15 dB
Bj = 10 MHz
MDS = -60 dBm
Rsoj = 112 km    60.4752 nmi
```

Figure 30. Jammer parameters (ALQ900.par).

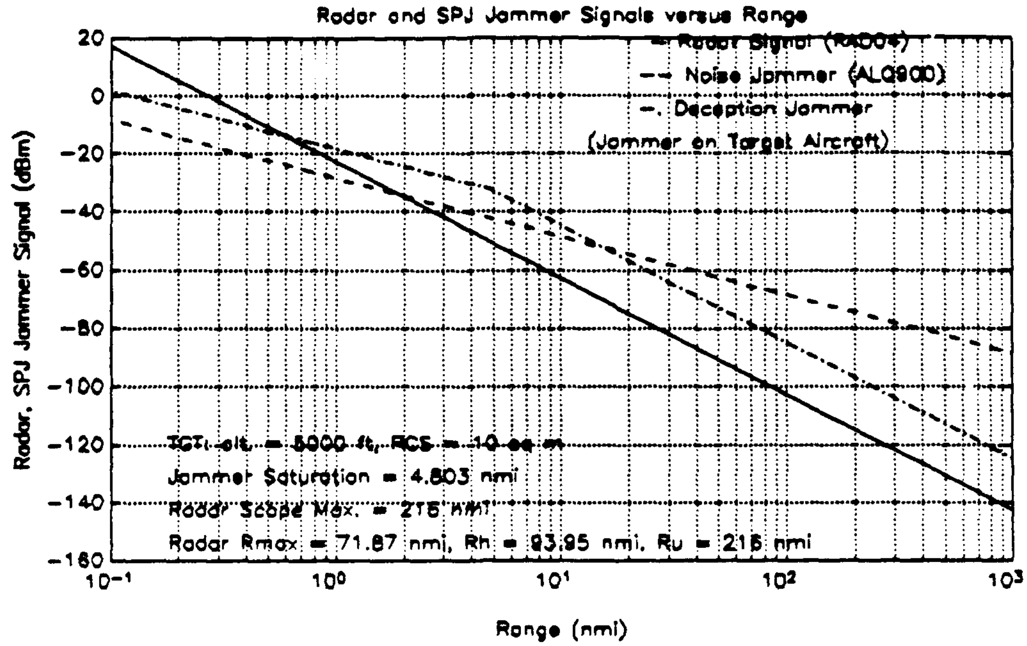

Figure 31. Radar return and SPJ signal.

radar file in the IMOM model. It should be noted however that a radar does not need to be created every time IMOM is run. IMOM stores all radars entered by run_infiles in the HOME/imom/data/imom/imom_imom directory. All radars addressable by IMOM are located in the HOME/imom/data/imom/elint directory. For IMOM version 2.3 at the time of this writing, any user created radar file must be copied to the HOME/imom/data/imom/elint directory in order for the radar to be displayed in the IMOM model ELNOT selection menu bar. The Unix command to perform this action is: cp *radarELNOT*.RAD ../elint, where the current directory is assumed to be HOME/imom/data/imom/imom_imom and *radarELNOT* is replaced by the actual radar ELNOT.

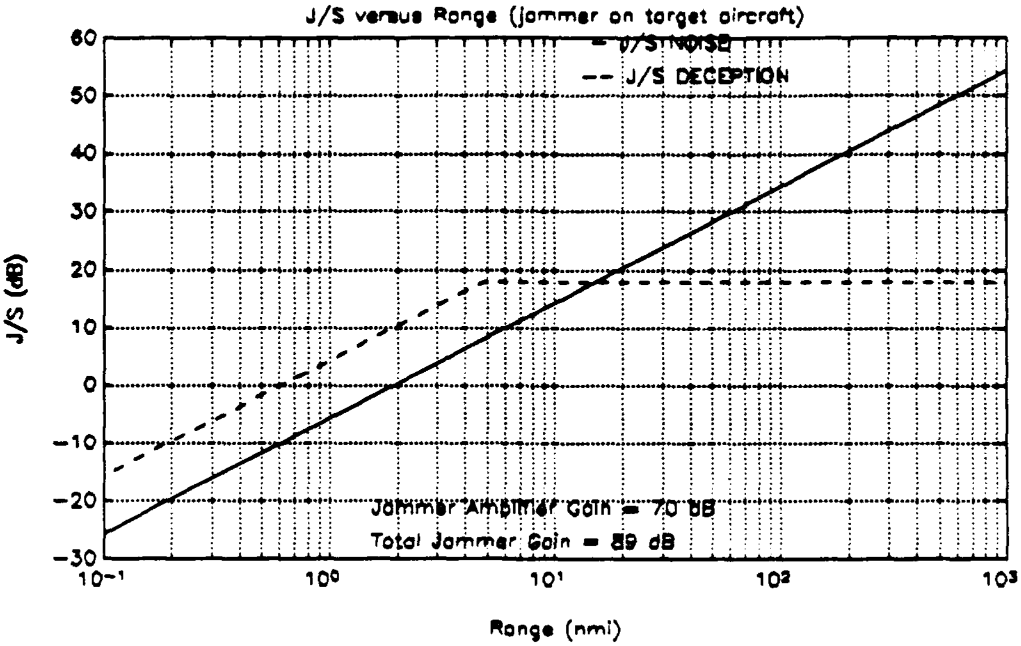

Figure 32. SPJ noise and deception J/S.

The jammer is entered into IMOM in the jammer exercises in the next chapter. After the radar is stored in IMOM, the EOB using the radar can be created.

Table 12 lists the sequence to create the EOB display. The table entries in all capital letters are IMOM menu selections that appear in the IMOM menu bar. The computer mouse is to locate the arrow pointer and the left mouse button is pressed to select.

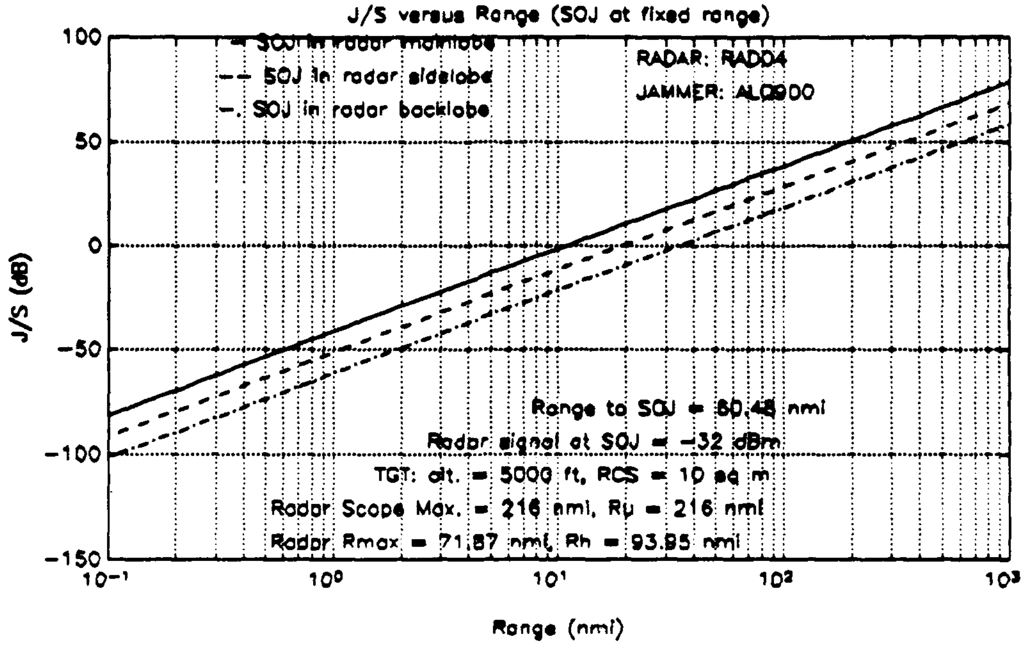

Figure 33. SOJ J/S for RAD04 and ALQ900.

TABLE 11
CREATE RADAR FILE IN IMOM
Execute "run_infiles"
Follow screen prompts
Enter radar ELNOT as RAD04
Set noise J/S to 10 dB

TABLE 12
IMOM DISPLAY OF GIVEN PARAMETERS
IMOM
UNCLASS
NEW MAP or RECALL MAP
Select desired map
CHANGE OB
ADD SITE
ELNOT
Select radar RAD04
Press ENTER three times for: BE NUMBER SITE NAME USE GRAPHIC INPUT CURSOR[Y]/N
Press left mouse button at desired radar location
PREV MENU
RINGS
RUN RINGS

Figure 34 shows the resulting IMOM RINGS display of the RAD04 radar. The IMOM displayed maximum radial length can then be compared to the calculated R_{max}, 71.87 nmi, shown in Figure 31 or 33. Table 13 outlines the method of measuring the maximum radial length in IMOM.

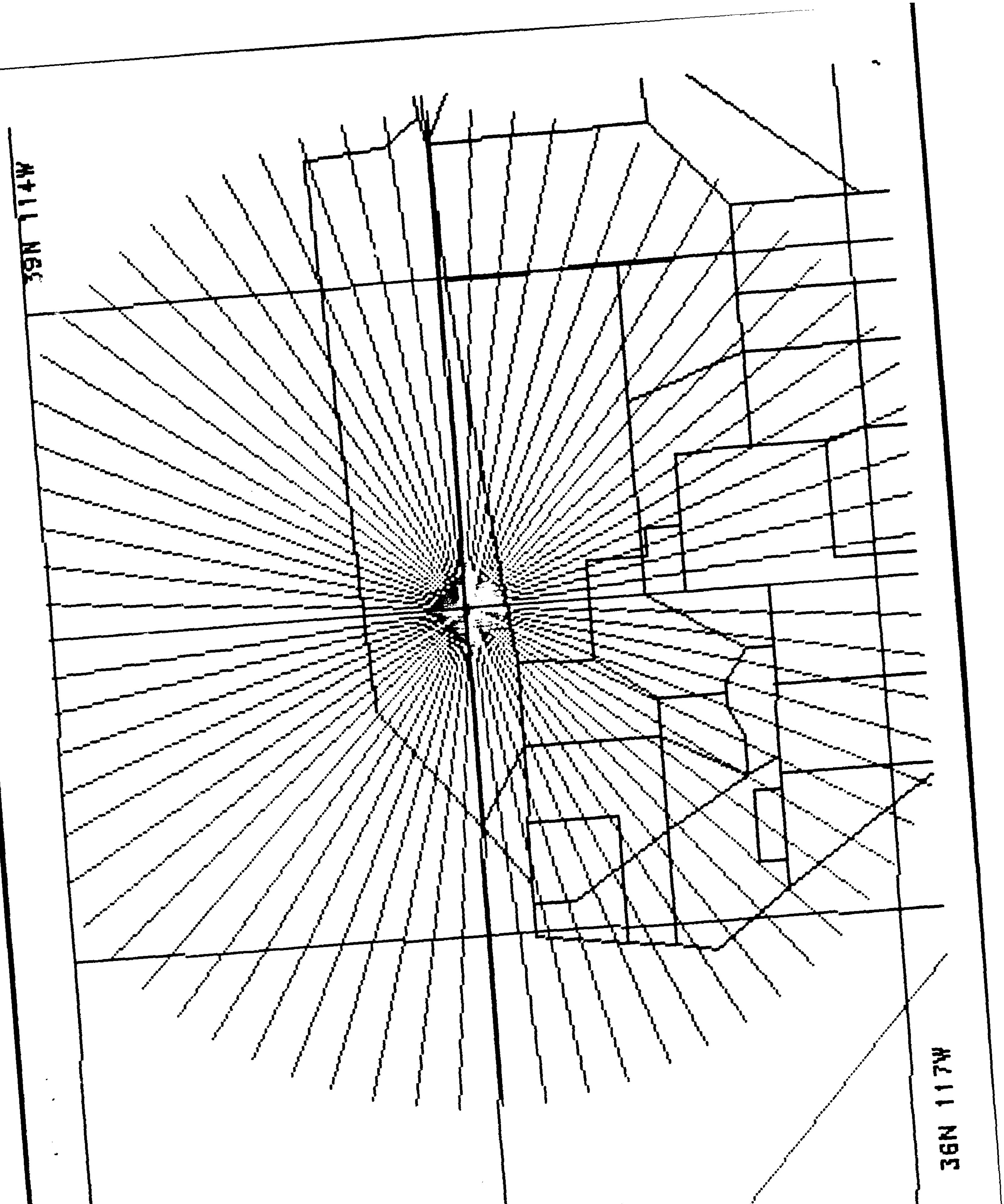

Figure 34. IMOM RINGS display for RADC4.

TABLE 13
MEASURING DISTANCE IN IMOM
UTILITIES
BEARING/DIS
Locate cursor at radar center, press left mouse button
Locate cursor at radial max, press left mouse button
Read distance in text window at screen bottom

The measured length of the radial maximum, R_{max}, is 71.5 nmi from the RINGS in Figure 34 using the BEARING/DIS feature. This is one way IMOM supports theory as well as clearly displaying radar detection characteristics relative to the radars geographical location.

All radars currently available in IMOM will appear in the menu bar at the left of the IMOM window when "ADD SITE" and "ELNOT" are selected to enter a radar. This process is repeated for all radars required in a particular EOB. If an additional weapon system is to be added to an existing radar site, the "ADD SITE", "WEAPON" menu selections are made, and the listing of available weapon systems will be displayed. The weapon is then located near the desired radar.

The effects of changing any of the radar parameters can be evaluated. Table 14 shows an example of some parameters that might be modified and the expected result of the parameter change.

TABLE 14	
RADAR PARAMETER CHANGE AND RESULT	
$16xP_{pk}$	Double R_{max}, 16x signal return
$16x\sigma$	Double R_{max}, 16x signal return
$16xS_{min}$	Decrease R_{max} by half
$4xA_e$	Double R_{max}, 16x signal return
16xf	Decrease R_{max} by half
$2xL_r$	0.84x R_{max}, half the signal return
$8xF_n$	0.594x R_{max}
10xI	1.77x R_{max}, 10x signal return
B/16	Double R_{max}

All of the above radar parameter changes can be observed by the IMOM RINGS displays. After making the necessary changes to the radar parameters by executing "run_infiles," the new R_{max} can be measured from the RINGS radials as listed in Table 13.

All of the above procedures can be performed on airborne radars as well. The airborne radars may not be affected by terrain or horizon LOS depending upon the altitude of the radar aircraft.

VII. ELECTRONIC WARFARE EXERCISES

A. SOJ

The process for viewing the effects of jamming is like that for the radar. The related parameters for the jamming theoretical calculations to be compared to the IMOM display are listed in Table 3. The jammer parameters are also entered into IMOM using the "run_infiles" program. Table 15 summarizes the important elements to create the SOJ jammer file.

TABLE 15
CREATE RADAR AND JAMMER FILES IN IMOM
Execute "run_infiles"
Verify jammer receiver bands
Verify jammer transmitter bands
Create ALQ900 jammer
Add a station
Load an oscillator
Noise, 9.5 GHz, not time dependent, 10 MHz spot width

Table 16 summarizes the sequence of actions to update the EOB display to include jamming of the RAD04 radar in Chapter V by the ALQ900 SOJ jammer created in this chapter. The table entries in all caps are IMOM menu selections, where the mouse is used to locate the arrow pointer and the left mouse button is pressed to make a selection.

TABLE 16
ADD ALQ900 JAMMER TO IMOM DISPLAY
Select PREV MENU until IMOM MAIN MENU is displayed
RINGS
DEL RINGS
PREV MENU
Select NO SOJ to change it to SOJ
Enter # of SOJ's, press ENTER
Select jammer
Y for mouse placement
Press left mouse button at jammer location
Set heading to face RAD04 radar (0° is up)
Enter altitude and AGL/MSL
NO

The RINGS feature must then be run to create the display with jammer effectiveness evaluated against radars in the EOB. Table 17 outlines the sequence to rerun IMOM RINGS, evaluating the effectiveness of the ALQ900 jammer against the RAD04 radar based on the jammer parameters and the jammer placement. Figure 35 shows the RINGS display for the RAD04 radar with the ALQ900 SOJ effectiveness.

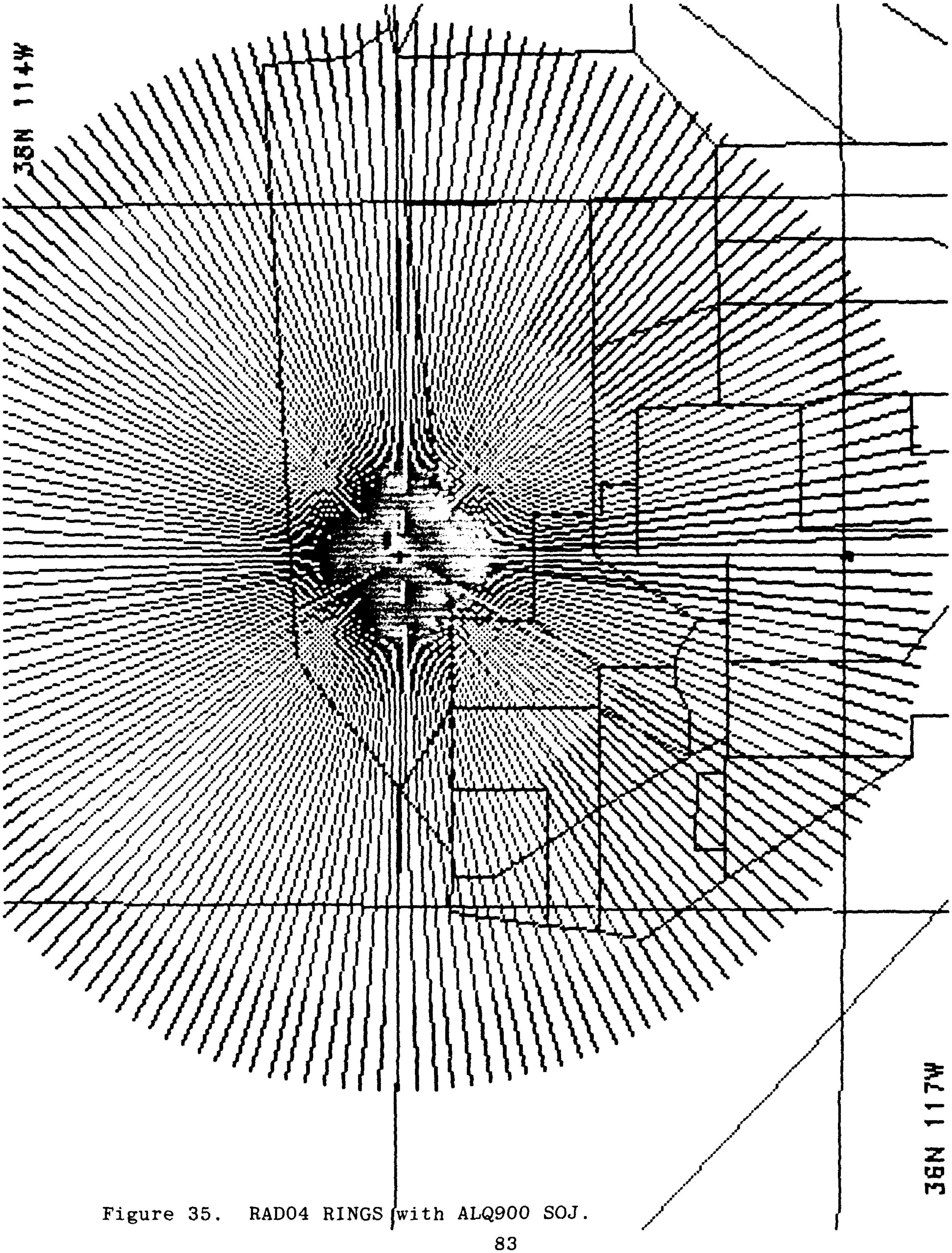

Figure 35. RAD04 RINGS with ALQ900 SOJ.

Table 18 summarizes the actions to measure the RAD04 radar burnthrough range against the ALQ900 SOJ in the ML, SL and BL of the radar. The measurements from this process are made from the display in Figure 36. The "x" symbol shows where the "BEARING/DIS" cursor is located when the measurements are made. Table 19 presents a comparison of the results calculated from theory and the IMOM display.

TABLE 17
IMOM DISPLAY OF SOJ JAMMER EFFECTS
RINGS
RUN RINGS
UTILITIES
ZOOM as necessary
BEARING/DIS

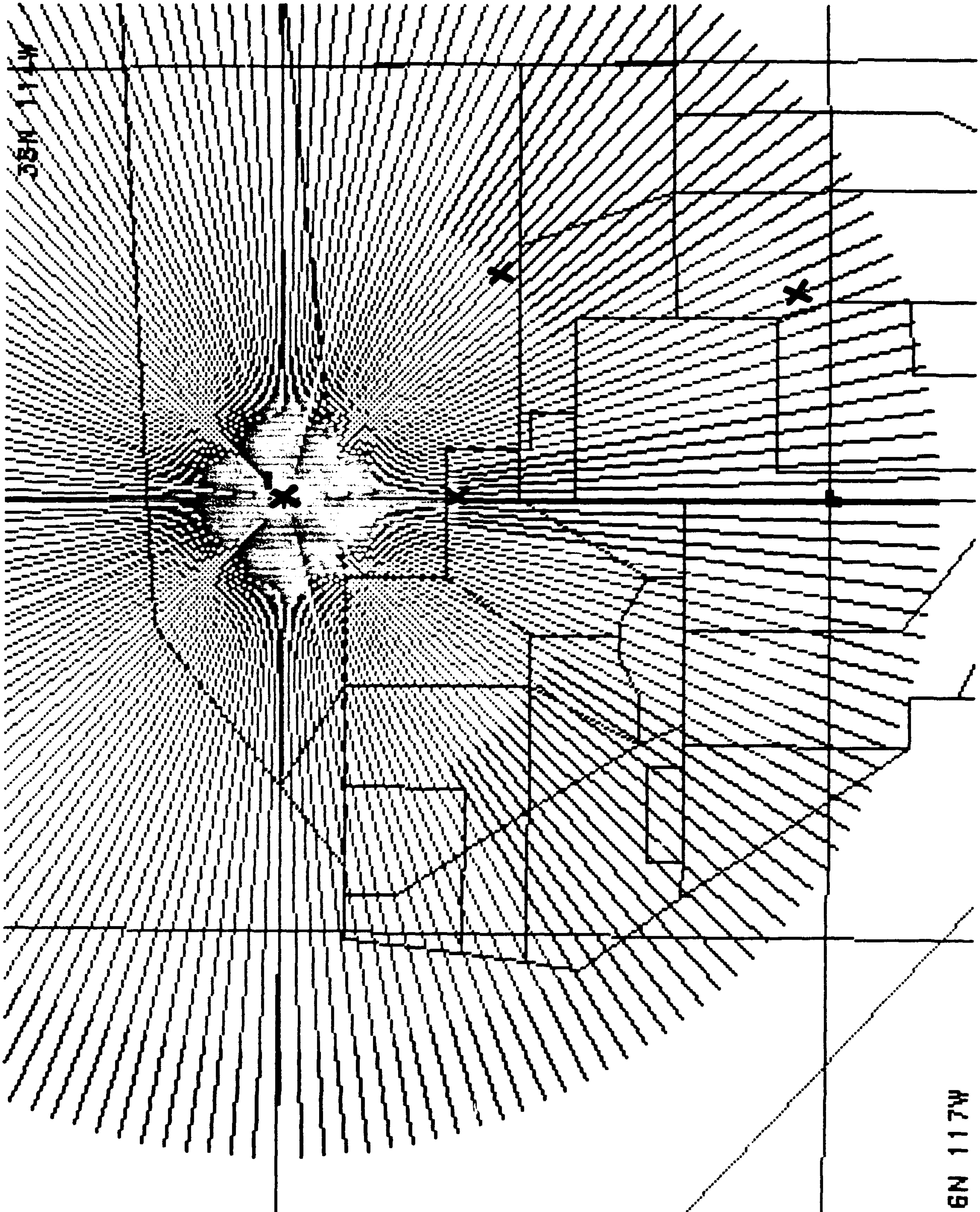

Figure 36. RINGS display with SOJ effectiveness used for BEARING/DIS measurements.

TABLE 18
MEASURING IMOM SOJ EFFECTIVENESS
Locate cursor at radar center, press left mouse button
Locate cursor at color change in mainlobe, press left mouse button
Read distance in text window at screen bottom
Compare distance to range at J/S_{ML}=10 in Figure 33
Locate cursor at radar center, press left mouse button
Locate cursor at color change in sidelobe, press left mouse button
Read "LAST LEG" distance in text window at screen bottom
Compare distance to range at to J/S_{SL}=10 in Figure 33
Locate cursor at radar center, press left mouse button
Locate cursor at color change in sidelobe, press left mouse button
Read "LAST LEG" distance in text window at screen bottom
Compare distance to range at J/S_{BL}=10 in Figure 33

TABLE 19		
THEORY AND IMOM BURNTHROUGH RANGE RAD04 VS ALQ900		
(J/S = 10 dB, P_j = 1000W)		
DIR.	THEORY	IMOM DISPLAY
ML	19 nmi	19 nmi
SL	34 nmi	33.8 nmi
BL	60 nmi	60.1 nmi

The data calculated from Table 18, and the graphics shown in Figures 34 and 35, show how IMOM can enhance understanding of the radar and jamming interaction as it would occur in an operational situation. This is because the calculated results show numerically the radar and jammer characteristics and IMOM displays the physical interaction representation of the radar and jammer characteristics.

The SOJ process described in this section provides the baseline for utilizing IMOM to view a SOJ scenario. The EOB can be expanded to multiple SOJ aircraft following the same sequence of events as described for the single SOJ case. As the student becomes more familiar with IMOM, more complicated scenarios can be created, up to a point where an actual EOB can be created.

Summarizing the SOJ characteristics presented, the theoretical calculation of SOJ signal level and J/S using jamming equations can be done by calculator or MATLAB program.

The student can then add each of the types of radars available in IMOM, HF, EW, TA, TT, and FC, and view the jamming effects by the RINGS display of the radar detection capabilities. The IMOM graphics are then compared to plots of the J/S for the given radar and jammer. This can be done for all radars and jammers in an EOB. Multiple SOJ aircraft and jammer parameter changes effects on the EOB can be observed.

One application of a laboratory assignment could be that an EOB has already been created, and consists of EW, HF and TA radars with TT and FC radars protecting the radar sites. The student could then be tasked to create a jammer using "run_infiles" that would be effective against the radars in the EOB. Effectiveness could be defined as a specific radar mainlobe burnthrough range, 10 nmi for example. Of course the student would be given a guideline of realistic jammer capabilities to follow when creating the jammer. Key to the jammer being effective would be frequency of operation, spot bandwidth, techniques loaded, antenna direction, antenna polarization, SOJ aircraft heading and distance from the radar sites.

B. SPJ

The utilization of SPJ is much simpler than for the SOJ. As described in detail in Chapter IV, any SPJ to be used must be resident in the SPJ_880129.DAT file. All effectiveness characteristics are contained in this file. It also must be remembered that SPJ effectiveness is only defined against TT

and FC radars, where the associated weapon to be jammed is contained in the SPJ file.

To understand the actual SPJ characteristics, the calculation of SPJ noise and deception signals at the radar should be done using the jamming equations. The J/S ratio can then be interpreted to understand the concept of radar burnthrough range and "constant gain" and "constant power" output characteristics.

An important note with respect to SPJ in IMOM is that only a single SPJ can be selected for any EOB. All TT and FC radars in the EOB are evaluated using this SPJ. The SPJ in this sense, can be assumed to be carried on the aircraft in each ROUTE created in IMOM.

C. *SPJ/SOJ*

The RINGS effects can be observed when both SOJ and SPJ are used in an EOB. There can also be multiple SOJ aircraft in the EOB as well as the SPJ. This scenario would be a combination of the SOJ and SPJ characteristics described in sections A and B of this chapter.

D. ADVANCED APPLICATION

An advanced application of IMOM, utilizing IMOM as it was designed, is electronic combat mission planning. In this case, a feature that could be exercised includes ingress and egress route planning for strike aircraft given a threat EOB. Aircraft parameters include altitude, heading and turnpoints.

Jamming capabilities include SOJ aircraft placement, SOJ jammer selection, and SPJ jammer selection. Airborne fighter FC and AWACS EW support aircraft could also be included. creating EOB is simply an extension of the basic theoretical and IMOM principles presented in this thesis. Figure 28 shows an example EOB with the features listed above.

VIII. SUMMARY

Radar and electronic warfare principles are presented in NPS lecture, coursework, and laboratories. This thesis presents a way to use the AFEWC IMOM computer program as an instructional asset to enhance student comprehension in the radar and EW curricula.

Radar theory has been described first to form a basis for comparison to IMOM. The radar and jamming equations were presented to summarize the calculations performed by IMOM in creating the color graphics display of radar and jammer interaction. The radar and jamming equations validate the performance of the IMOM program, as well as providing a review for coursework.

A description of some of the most important display characteristics of IMOM that enhance a students understanding of radar and jamming principles were presented. These principles included radar maximum detection range based on radar operating parameters, and SPJ and SOJ jamming effectiveness based on the radar to jammer geometry and jammer operating parameters.

The radar and jamming equation calculations were carried out by the MATLAB program rdrrng.m to produce graphical radar and jamming performance data. J/S ratios for SOJ are calculated as a function of range and are further used to determine radar burnthrough range. This graphical data was

then compared to IMOM RINGS and ROUTE display features in order to graphically observe the physical interaction of radar and jammer.

An example of using the rdrrng.m program to calculate theoretical performance of a given radar and jammer was described. The procedure to create an IMOM display of the radar and jammer interaction was outlined. The process of analyzing a single radar and jammer formed the basis for creating more complex IMOM EOB displays.

IX. CONCLUSIONS

The teaching of Radar and EW will be enhanced by utilizing the AFEWC IMOM computer program at NPS. By incorporating IMOM, radar and jamming principles are clearly presented by IMOM color graphics displays. The IMOM RINGS and ROUTE features are the primary display characteristics providing a clearer two dimensional display of the physical interaction of radars and jammers. The addition of geopolitical boundaries and terrain characteristics for the specified geographical area enhance the capability of IMOM.

NPS coursework is enhanced by IMOM display capabilities. Radar and EW principles presented in coursework and lecture hours are supported by the IMOM displays because it is based on the same radar range and jamming equations presented in class. The output of the IMOM model as presented in the display were validated in this thesis. This was done by comparing the IMOM displayed radar detection capabilities, to the estimated detection capabilities from the radar and jamming equations.

Further evidence of the relevance of IMOM to NPS radar and EW curricula is the fact that IMOM is used operationally by the U.S. Air Force. IMOM is an active project still in further development with the Advanced Modelling Division of the U.S. Air Force Electronic Warfare Center, San Antonio, Texas. In this capacity, enhancements to the IMOM computer

program could be done by students at NPS as research projects and thesis topics. Subroutines and modules could be developed at NPS for incorporation into the IMOM model. This would require NPS obtaining the IMOM source code from AFEWC, or at least documented input and output requirements for any program modules to be developed at NPS.

APPENDIX A

rdrrng.m MATLAB Program

MATLAB rdrrng.m program for IBM PC and compatible computers running MATLAB. Note: due to the length of some lines of code in the program, the line is continued on the next line. This is not how it appears in the actual MATLAB program. The semicolon designates the true end of a line of code. Some DOS commands are used for file operations. DOS commands need to be changed to UNIX commands if the program is to be used with the UNIX operating system.

```
% ************************************************************
% * This is a MATLAB program to plot the radar return,       *
% * jammer return, and J/S versus range,                     *
% * as calculated by the radar range and jamming equations.  *
% * The output is compared to the IMOM RINGS display output. *
% ************************************************************
% * Last edited: 10 SEP 92                                   *
% * Written by: Gregg A. Van Splinter                        *
% * Naval Postgraduate School                                *
% * Monterey, California                                     *
% ************************************************************

clg             %CLEAR GRAPH WINDOW
echo off        %TURN OFF SCREEN ECHO

% START MAIN PROGRAM LOOP
continue = 'y';
while continue == 'y'

clc;            %CLEAR COMMAND WINDOW
% DISPLAY PROGRAM HEADER ON SCREEN
fprintf('THIS PROGRAM PLOTS THE RADAR RANGE AND JAMMING\n');
fprintf('EQUATIONS AS FUNCTIONS OF RANGE TO TARGET.\n\n');
fprintf('The input radar and jammer parameters match the\n');
fprintf('parameters entered in IMOM.  The radar ELNOT and\n');
fprintf('jammer designation should match those used in IMOM.');
fprintf('\n\nTo compare results to the IMOM RINGS display:');
fprintf('\n  * Compare Rmax with RINGS radial max. length');
fprintf('\n  * For SOJ, read range at required J/S');
fprintf('\n    Compare range to ML, SL or BL RINGS radial');
fprintf('\n\n\n');

radardata=input('Recall or Create Radar Data (R/C) ','s');

if radardata == 'c'     % CREATE .PAR FILE FOR INPUT DATA

radarnam=input('Type ELNOT of radar ','s');
```

```
% IF PREVIOUS FILE OF SAME NAME IS NOT DELETED, ANY FURTHER
% meta COMMANDS WILL APPEND THOSE FILES TO EXISTING FILE
delfiletext=['Delete previous ',radarnam,'.met graph file? (Y/N)'];
delfile=input(delfiletext,'s');
if delfile == 'y'
eval(['!del ',radarnam,'.met']); %DOS DELETE FILE COMMAND
end

% ****************************************************************
% ASK FOR ALL RELATED RADAR PARAMETERS TO CREATE RADAR FILE

% DELETE PREVIOUS .PAR FILE OF SAME NAME TO AVOID APPENDING
% NEW DATA TO OLD FILE
eval(['!del ',radarnam,'.par']);

% CREATE .PAR FILE WITH INPUT RADAR NAME
eval(['diary ',radarnam,'.par']);
clc;    % CLEAR COMMAND WINDOW
% WRITE FILE NAME (WHICH IS ALSO RADAR ELNOT) TO DATA FILE
radparfil=[' RADAR: ',radarnam];
disp(radparfil);
diary off;

% ******************************************************
% FORMAT OF RADAR DATA FOR OUTPUT TO .PAR FILE
% CREATE FILENAME FOR fprintf STATEMENT

fpname=['''',radarnam,'.par'''];

% FORMAT OF OUTPUT STRING FOR fprintf STATEMENT
% fpformat=[''' TEXT HERE = format UNIT LINEFEED'''];
% FORMAT OF fprint STATEMENT TO SEND DATA TO .PAR FILE
% eval(['fprintf(',fpname,',',fpformat,',xx)']);
% ******************************************************

% INPUT RADAR PARAMETERS AND OUTPUT EACH TO radarnam.PAR FILE

hant=input('Enter Antenna Height (m) ');
fpformat=[''' Ant. Ht. = %g m    %g ft\n'''];
hantft=hant/.3048;
eval(['fprintf(',fpname,',',fpformat,',hant,hantft)']);

ptkw=input('Enter Transmitter Peak Power (kW) ');
fpformat=[''' Ppk = %g kW\n'''];
eval(['fprintf(',fpname,',',fpformat,',ptkw)']);
ptw=ptkw*1000; % CONVERT POWER TO WATTS

gtdb=input('Enter Transmit Antenna Gain (dB) ');
gt=10^(gtdb/10);          % CONVERT DB TO RATIO
fpformat=[''' Gt = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',gtdb)']);
```

```
grdb=input('Enter Receive Antenna Gain (dB) ');
gr=10^(grdb/10);          % CONVERT DB TO RATIO
fpformat=[''' Gr = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',grdb)']);

f=input('Enter RF Frequency (GHz) ');

fpformat=[''' f = %g GHz\n'''];
eval(['fprintf(',fpname,',',fpformat,',f)']);

b=input('Enter Receiver Bandwidth (Hz) ');
fpformat=[''' Br = %g Hz\n'''];
eval(['fprintf(',fpname,',',fpformat,',b)']);

% CALCULATE PULSEWIDTH
pw=1/b;
fpformat=[''' PW = %g s\n'''];
eval(['fprintf(',fpname,',',fpformat,',pw)']);

ldb=input('Enter Receiver Losses (dB) ');
l=10^(ldb/10);          % CONVERT DB TO RATIO
fpformat=[''' Lr = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',ldb)']);

ndb=input('Enter Receiver Noise Figure (dB) ');
n=10^(ndb/10);          % CONVERT DB TO RATIO
fpformat=[''' Fn = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',ndb)']);

intdb=input('Enter Integration Gain (dB) ');
int=10^(intdb/10);          % CONVERT DB TO RATIO
fpformat=[''' I = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',intdb)']);

sndb=input('Enter Signal to Noise Ratio (dB) ');
ston=10^(sndb/10);          % CONVERT DB TO RATIO
fpformat=[''' S/N = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',sndb)']);

sltomldb=input('Enter Sidelobe dB Down From Mainlobe (dB) ');
fpformat=[''' Sidelobe dB down = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',sltomldb)']);
sltoml=10^(-sltomldb/10);          % CONVERT DB TO RATIO

bltomleldb=input('Enter Backlobe EL. dB Down From Mainlobe (dB) ');
fpformat=[''' Backlobe EL. dB down = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',bltomleldb)']);
bltomlel=10^(-bltomleldb/10);          % CONVERT DB TO RATIO

bltomlazdb=input('Enter Backlobe AZ. dB Down From Mainlobe (dB) ');
fpformat=[''' Backlobe AZ. dB down = %g dB\n'''];
eval(['fprintf(',fpname,',',fpformat,',bltomlazdb)']);
```

```
bltomlaz=10^(-bltomlazdb/10);          % CONVERT DB TO RATIO

bltoml=(bltomlel+bltomlaz)/2; %CALCULATE BACKLOBE AVERAGE GAIN

runambkm=input('Enter Unambiguous Range (km) ');
runambnmi=runambkm/1.852; % convert to nmi
fpformat=[''' Ru = %g km    %g  nmi\n'''];
eval(['fprintf(',fpname,',',fpformat,',runambkm,runambnmi)']);

scopekm=input('Enter Radar Scope Range (km) ');
scopenmi=scopekm/1.852; % convert to nmi
fpformat=[''' Scope Range = %g km   %g nmi\n'''];
eval(['fprintf(',fpname,',',fpformat,',scopekm,scopenmi)']);

% Calculate PRF
prf=3E8/(2*runambkm*1000);
fpformat=[''' PRF = %g Hz\n'''];
eval(['fprintf(',fpname,',',fpformat,',prf)']);

% CALCULATE AVERAGE POWER
pavw=ptw*pw*prf;
fpformat=[''' Pav = %g W\n'''];
eval(['fprintf(',fpname,',',fpformat,',pavw)']);

t=input('Enter Target RCS (square meters) ');
fpformat=[''' RCS = %g sq m\n'''];
eval(['fprintf(',fpname,',',fpformat,',t)']);

alt=input('Enter Target Altitude (ft) ');
fpformat=[''' Alt. = %g ft\n'''];
eval(['fprintf(',fpname,',',fpformat,',alt)']);

% SAVE RADAR PARAMETERS TO radarnam.MAT FILE
% THIS IS THE FILE READ BY MATLAB WHEN recall file IS SELECTED
parlist1=[' radarnam hant ptw gt gr f b pw l n int ston'];
parlist=[parlist1,' sltoml bltoml scopenmi runambnmi prf pavw t
alt'];
eval(['save ',radarnam,parlist]);

clc;    % CLEAR COMMAND WINDOW
savfildisp=['Radar  parameters  have  been  saved  to  file:
',radarnam,'.par'];
disp(savfildisp);
pause(3)
eval(['type ',radarnam,'.par']);
fprintf('\n\nPress ENTER to continue')
pause
clc;    % CLEAR COMMAND WINDOW

elseif radardata == 'r'         % RECALL EXISTING RADAR DATA FILE
```

```
radarnam=input('Type ELNOT of radar ','s');
eval(['load ',radarnam,'.mat']);
clc;    % CLEAR COMMAND WINDOW
% DISPLAY RADAR PARAMETERS FROM radarnam.par FILE
eval(['type ',radarnam,'.par']);
fprintf('\n\nPress ENTER to continue')
pause
clc;    % CLEAR COMMAND WINDOW

end     % END INPUT OF RADAR PARAMETERS

% ************************************************************
% INPUT JAMMER RELATED PARAMETERS
% NOTE: JAMMER AMPLIFIER GAIN IS NOT A VARIABLE IN IMOM!!!!

jammerdata=input('Recall or Create Jammer Data (R/C) ','s');

if jammerdata == 'c'            % CREATE JAMMER PARAMETER FILE

jammname=input('Type Jammer Designation (i.e. ALQ100) ','s');
eval(['!del ',jammname,'.par']);
eval(['diary ',jammname,'.par']);

clc;    % CLEAR COMMAND WINDOW
jamparfil=[' Jammer: ',jammname];
disp(jamparfil);
diary off;

fpjname=['''',jammname,'.par'''];
% FORMAT OF JAMMER DATA FOR OUTPUT TO .PAR FILE
%eval(['fprintf(',fpjname,',',fpjformat,',xx)'])

gjrdb=input('Enter Jammer Rx Antenna Gain (dB) ');
gjr=10^(gjrdb/10);
fpjformat=['''\n Gjr = %g dB\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',gjrdb)'])

ljrdb=input('Enter Jammer Rx Line Loss (dB) ');
ljr=10^(ljrdb/10);
fpjformat=[''' Ljr = %g dB\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',ljrdb)'])

gjadb=input('Enter Jammer Amplifier Gain (dB) ');
gja=10^(gjadb/10);
fpjformat=[''' Gja = %g dB\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',gjadb)'])

pjw=input('Enter Jammer Amplifier Power (W) ');
fpjformat=[''' Pj = %g W\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',pjw)'])
```

```
ljtdb=input('Enter Jammer Tx Line Loss (dB) ');
ljt=10^(ljtdb/10);
fpjformat=[''' Ljt = %g dB\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',ljtdb)'])

gjdb=input('Enter Jammer Tx Antenna Gain (dB) ');
gj=10^(gjdb/10);
fpjformat=[''' Gj = %g dB\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',gjdb)'])

bj=input('Enter Jammer Spot Bandwidth (MHz) ');
fpjformat=[''' Bj = %g MHz\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',bj)'])
bj=bj*1E6; % PUTS BW OF JAMMER INTO Hz

jmdsdbm=input('Enter Jammer Minimum Discernable Signal (dBm) ');
jmds=(10^(jmdsdbm/10))/1000; % CONVERT FROM dBm to W
fpjformat=[''' MDS = %g dBm\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',jmdsdbm)'])

rsojkm=input('Enter SOJ Range (km) [1.852km/nmi] ');
rsojnmi=rsojkm/1.852; % CONVERT FROM km TO nmi
fpjformat=[''' Rsoj = %g km    %g nmi\n'''];
eval(['fprintf(',fpjname,',',fpjformat,',rsojkm,rsojnmi)'])

jamparlist1=[' jammname pjw gjdb gj gjrdb gjr gjadb gja'];
jamparlist=[jamparlist1,' ljtdb ljt ljrdb ljr bj jmds rsojnmi'];
eval(['save ',jammname,jamparlist]);

clc;    % CLEAR COMMAND WINDOW
savjfildisp=['Jammer parameters have been saved to file:
',jammname,'.par'];
disp(savjfildisp);
eval(['type ',jammname,'.par']);
fprintf('\n\nPress ENTER to continue')
pause
clc;    % CLEAR COMMAND WINDOW

elseif jammerdata == 'r'       % RECALL EXISTING jammname.par FILE

jammname=input('Type Jammer Designation (i.e. ALQ100) ','s');
eval(['load ',jammname,'.mat']);
clc;    % CLEAR COMMAND WINDOW
eval(['type ',jammname,'.par']);
fprintf('\n\nPress ENTER to continue');
pause
clc;    % CLEAR COMMAND WINDOW

end     % END INPUT OF JAMMER PARAMETERS

wavelength=3E8/(f*1E9); % in meters
```

```
% ************************************************************
% CALCULATE RADAR MAXIMUM DETECTION RANGE IN nmi GIVEN S/N
% wavelength is m and t is sq m
k=1.38E-23; % BOLTZMANS CONSTANT, Joules/degrees K
temp=290; % degrees K

rmax=((ptw*gt*gr*wavelength^2*t*int)/((4*pi)^3*ston*k*temp*b*n*l)
)^(1/4);
rmax=rmax/1852; % CONVERT FROM m TO nmi

% ************************************************************
% THERE WILL BE 50 POINTS BETWEEN .1 & 1000, r=[.1 1 10 100 1000]
r=logspace(-1,3);

% ************************************************************
% CALCULATE TARGET SIGNAL RETURN VERSUS RANGE
signal=(ptw*gt*gr*wavelength^2*t*int/(l*1852^4*(4*pi)^3))./r.^4;
% convert signal from watts to dBm
signaldbm = 10*log10(signal.*1000);

% ************************************************************
% CALCULATE SIGNAL POWER FROM NOISE JAMMER ON TARGET AIRCRAFT
j=(pjw*gj*gr*(wavelength^2/1852^2)*b)./((((4*pi)^2)*bj*l*ljt*(r.^2
));
% convert signal from watts to dBm
jdbm = 10*log10(j.*1000);

% ************************************************************
% CALCULATE J/S versus RANGE
jtos = j./signal;
% convert signal dB
jtosdb = 10*log10(jtos);

% ************************************************************
% CALCULATE J/S FOR NOISE JAMMER ON STANDOFF AIRCRAFT
% ON LINE OF SIGHT WITH TARGET AIRCRAFT AT DIFFERENT RANGE
jsoj=(pjw*gj*4*pi*b*1852^2*r.^4)./(ptw*gt*bj*t*ljt*int*rsojnmi^2);
% convert signal dB
jsojdb = 10*log10(jsoj);

% ************************************************************
% CALCULATE J/S FOR NOISE JAMMER ON STANDOFF AIRCRAFT
% NOT ON LINE OF SIGHT WITH TARGET AIRCRAFT AND
% AT DIFFERENT RANGE (SIDELOBE)
jsojsl=(pjw*gj*4*pi*b*1852^2*r.^4*sltoml)./(ptw*gt*bj*t*ljt*int*r
sojnmi^2);
% convert signal dB
jsojsldb = 10*log10(jsojsl);
```

```
% ***********************************************************
% CALCULATE J/S FOR NOISE JAMMER ON STANDOFF AIRCRAFT
% IN BACKLOBE OF RADAR
jsojbl=(pjw*gj*4*pi*b*1852^2*r.^4*bltoml)./(ptw*gt*bj*t*ljt*int*r
sojnmi^2);
% convert signal dB
jsojbldb = 10*log10(jsojbl);

% ***********************************************************
% CALCULATE RADAR SIGNAL AT JAMMER RECEIVER USING rsoj
rdet=(ptw*gt*wavelength^2*gjr)/(1852^2*(4*pi)^2*ljr*rsojnmi^2);
rdet=10*log10(rdet*1000); % CONVERT W TO dBm

% ***********************************************************
% CALCULATE JAMMER SATURATION RANGE
rsat=((ptw*gt*wavelength^2*gjr*gja)/(pjw*(4*pi)^2*ljr))^(1/2);
rsat=rsat/1852; % nmi


% ***********************************************************
% CALCULATE RETURN FROM CONSTANT GAIN JAMMER
x=rsat:10:1000;
cgsig=(ptw*gt*gr*wavelength^4*gjr*gja*gj/(1852^4*(4*pi)^4*l*ljr*l
jt))./x.^4;
cgsigdbm=10*log10(cgsig*1000); % CONVERT FROM W TO dBm

% ***********************************************************
% CALCULATE RETURN FROM CONSTANT POWER JAMMER
y=.1:.1:rsat;
cpsig=(pjw*gj*gr*wavelength^2/(1852^2*(4*pi)^2*l*ljt))./y.^2;
cpsigdbm=10*log10(cpsig*1000); % CONVERT FROM W TO dBm

% ***********************************************************
%CALCULATE J/S FOR DECEPTION JAMMER
% RANGE GREATER THAN SATURATION
jtoscg=((wavelength^2*gjr*gja*gj)/(4*pi*ljr*ljt*t*int)).*ones(cgs
ig);
jtoscgdb=10*log10(jtoscg);
% RANGE LESS THAN SATURATION
jtoscp=((pjw*gj*1852^2*4*pi)/(ptw*gt*t*ljt*int)).*y.^2;
jtoscpdb=10*log10(jtoscp);

% ***********************************************************
% CALCULATE HORIZON LIMITED LINE OF SIGHT FOR GIVEN
% RADAR ANTENNA HEIGHT AND TARGET ALTITUDE
rh=(2*hant*8.5E6)^(1/2)+(2*alt*.3048*8.5E6)^(1/2); %RANGE IN m
rh=rh/1852; %CONVERT m TO nmi

% ***********************************************************
% plot radar return, jamming signal versus range on a semilog plot
semilogx(r,signaldbm,'-',r,jdbm,'--',x,cgsigdbm,'-.',y,cpsigdbm,'
-.');
```

```
% ***********************************************************
% ADD DISPLAY ATTRIBUTES TO SIGNALS PLOT

grid
title('Radar and SPJ Jammer Signals versus Range');
xlabel('Range (nmi)');
ylabel('Radar, SPJ Jammer Signal (dBm)');
radarlabel=[' - Radar Signal (',radarnam,')'];
text(0.6,0.9,radarlabel,'sc');
jammerlabel=['-- Noise Jammer (',jammname,')'];
text(0.6,0.85,jammerlabel,'sc');
text(0.6,0.8,'-. Deception Jammer','sc');
text(0.55,0.75,'(Jammer on Target Aircraft)','sc');
rcslabel=['RCS = ',num2str(t),' sq m'];
sclabel=['Radar Scope Max. = ',num2str(scopenmi),' nmi'];
altlabel=['TGT: alt. = ',num2str(alt),' ft'];
rhlabel=['Rh = ',num2str(rh),' nmi'];
rulabel=['Ru = ',num2str(runambnmi),' nmi'];
altrcslabel=[altlabel,', ',rcslabel];
rmaxlabel=['Radar Rmax = ',num2str(rmax),' nmi'];
rdetlabel=['Jammer Smds = ',num2str(rdet),' dBm'];
rsatlabel=['Jammer Saturation = ',num2str(rsat),' nmi'];
rmaxrhrulabel=[rmaxlabel,', ',rhlabel,', ',rulabel];
text(0.15,0.3,altrcslabel,'sc');
text(0.15,0.25,rsatlabel,'sc');
text(0.15,0.2,sclabel,'sc');
text(0.15,0.15,rmaxrhrulabel,'sc');

pause %STOP TO LOOK AT PLOT OF SIGNAL RETURNS

asktosave=['Save signal return graph to ',radarnam,'.met file?
(Y/N)'];
saveans=input(asktosave,'s');
if saveans == 'y'
eval(['meta ',radarnam,])
end
clc;    % CLEAR COMMAND WINDOW

% ***********************************************************
% PLOT J/S VERSUS RANGE FOR JAMMER ON ATTACK AIRCRAFT
semilogx(r,jtosdb,'-',y,jtoscpdb,'--',x,jtoscgdb,'--');

% ***********************************************************
% ADD DISPLAY ATTRIBUTES TO SPJ J/S PLOT

grid
title('J/S versus Range (jammer on target aircraft)');
xlabel('Range (nmi)');
ylabel('J/S (dB)');
noiselabel=[' - J/S NOISE'];
text(0.55,0.9,noiselabel,'sc');
deceplabel=['-- J/S DECEPTION'];
```

```
text(0.55,0.85,deceplabel,'sc');
gainlabel=['Jammer Amplifier Gain = ',num2str(gjadb),' dB'];
text(0.35,0.2,gainlabel,'sc');
tgain=gjrdb-ljrdb+gjadb-ljtdb+gjdb;
tgainlabel=['Total Jammer Gain = ',num2str(tgain),' dB'];
text(0.35,0.15,tgainlabel,'sc');
pause %STOP TO LOOK AT PLOT OF SIGNAL RETURNS
asktosavetoo=['Save  SPJ  J/S  graph  to  ',radarnam,'.met  file?
(Y/N)'];
saveanstoo=input(asktosavetoo,'s');
if saveanstoo == 'y'
eval(['meta ',radarnam,])
end
clc;    % CLEAR COMMAND WINDOW

% ***********************************************************
% PLOT J/S VERSUS RANGE FOR SOJ AIRCRAFT
semilogx(r,jsojdb,'-',r,jsojsldb,'--',r,jsojbldb,'-.');

% ***********************************************************
% ADD DISPLAY ATTRIBUTES TO SOJ J/S PLOT

grid
title('J/S versus Range (SOJ at fixed range)');
xlabel('Range (nmi)');
ylabel('J/S (dB)');
sojlabel=[' - SOJ in radar mainlobe'];
text(0.2,0.9,sojlabel,'sc');
sojsllabel=['-- SOJ in radar sidelobe'];
text(0.2,0.85,sojsllabel,'sc');
sojbllabel=['-. SOJ in radar backlobe'];
text(0.2,0.8,sojbllabel,'sc');
rdrlabel=['RADAR: ',radarnam];
jammlabel=['JAMMER: ',jammname];
scrulabel=[sclabel,', ',rulabel];
rmaxrhlabel=[rmaxlabel,', ',rhlabel];
text(0.6,0.875,rdrlabel,'sc');
text(0.6,0.825,jammlabel,'sc');
text(0.35,0.25,altrcslabel,'sc');
text(0.25,0.2,scrulabel,'sc');
text(0.25,0.15,rmaxrhlabel,'sc');
sojrng=['Range to SOJ = ',num2str(rsojnmi),' nmi'];
sojmds=['Radar signal at SOJ = ',num2str(rdet),' dBm'];
text(0.5,0.35,sojrng,'sc');
text(0.4,0.3,sojmds,'sc');
pause %STOP TO LOOK AT PLOT OF SOJ J/S

fprintf('\nThe  SOJ_JTOS.met  file  appends  only  the  SOJ  J/S
graphs\n');
fprintf('to one another.\n');
```

```
delsojmettext=['DELETE previous SOJ_JTOS.met file? (Y/N)'];
delsojmet=input(delsojmettext,'s');
if delsojmet == 'y'
!del SOJ_JTOS.met;
end

asktosavetre=['Save SOJ J/S graph to ',radarnam,'.met file?
(Y/N)'];
saveanstre=input(asktosavetre,'s');
if saveanstre == 'y'
eval(['meta ',radarnam,])
end
asktosaveth=['Save SOJ J/S graph to SOJ_JTOS.met file? (Y/N)'];
saveansth=input(asktosaveth,'s');
if saveansth == 'y'
meta SOJ_JTOS
end

continue=input('Rerun program? (Y/N)','s');
% IF YES, GO BACK TO BEGINNING OF PROGRAM
clc;    % CLEAR COMMAND WINDOW
end % END OVERALL WHILE LOOP
```

APPENDIX B

Radar Parameters Summary from run_infiles

This appendix includes each of the display screens presented to the user after all IMOM radar parameters have been set while executing "run_infiles." These screens are also displayed when individual radar parameter changes are made. An example of the parameters stored in an IMOM *ELNOT*.RAD file are listed in these display screens.

```
                         CLASSIFICATION
ELNOT RADAR FILE                                       PAGE 1 OF 5
  1 NATO NICKNAME OR DESIGNATOR                   <NICKNAME/DESIG>
  2 EMITTER FUNCTION                                          <AA>
  3 ANTENNA HEIGHT (M)                                     <NN.NN>
  4 PEAK POWER (ANTENNA FEED PORT IN KWATTS)              <NNN.NN>
  5 BEAMWIDTH IN AZIMUTH (DEG)                              <N.NN>
  6 BACKLOBE LEVEL IN ELEVATION (DB DOWN)                  <NN.NN>
  7 BACKLOBE LEVEL IN AZIMUTH (DB DOWN)                    <NN.NN>
  8 BW OF DOPPLER FILTER -OR- FINAL AMP (HZ)          <NNNNNNNN.NN>
  9 INTEGRATION GAIN (DB)                                  <NN.NN>
 10 RADAR RECEIVER LOSSES (DB)                              <N.NN>

                         CLASSIFICATION

PRESS RETURN TO CONTINUE WITH PAGE ONE
```

First Half of Page 1 Radar Parameters

```
                         CLASSIFICATION

 11 NOISE FIGURE FOR THE RADAR (DB)                         <N.NN>
 12 S/N WITHOUT INTEGRATION (DB)                           <NN.NN>
    GIVEN:  PROBABILITY OF DETECTION                        <0.NN>
                 PROBABILITY OF FALSE ALARM                 <0.NN>
 13 MAXIMUM SCOPE LIMIT (KM)                              <NNN.NN>
 14 MAXIMUM UNAMBIGUOUS RANGE (KM)                        <NNN.NN>
 15 NUMBER OF BEAMS                                            <N>
 16 NUMBER OF SIDELOBES                                        <N>
 17 MAX & MIN ELEVATION ANGLES (DEG)                <NN.N>  <NN.N>
 18 WEAPON SYSTEM                                  <WEAPON SYSTEM>
 19 CLASSIFICATION                                <CLASSIFICATION>

                         CLASSIFICATION

TO EDIT TYPE LINE NUMBER AND PRESS RETURN

TO EXIT TYPE 99 AND PRESS RETURN

FOR NEXT SCREEN PRESS RETURN
```

Second Half of Page 1 Radar Parameters

CLASSIFICATION

ELNOT RADAR FILE PAGE 2 OF 5

BEAM NUMBER	N	N
1 MOST PROBABLE RF FREQUENCY (GHZ)	<N.NN>	<N.NN>
2 ANTENNA POLARIZATION	AAA	AAA
3 ELEVATION BORESIGHT ANGLE (DEGREES)	<NN.NN>	<NN.NN>
4 BEAMWIDTH IN ELEVATION (DEGREES)	<N.NN>	<N.NN>
5 TRANSMITTER ANTENNA GAIN (DB)	<NN.NN>	<NN.NN>
6 RECEIVER ANTENNA GAIN (DB)	<NN.NN>	<NN.NN>

CLASSIFICATION

TO EDIT TYPE THE BEAM NUMBER AND PRESS RETURN

TO EXIT TYPE 99 AND PRESS RETURN

FOR NEXT SCREEN PRESS RETURN

Page 2 Radar Parameters

CLASSIFICATION

ELNOT RADAR FILE PAGE 3 OF 5

SIDELOBE	N	N
1 SIDELOBE POSITION (DEGREES)	<N.NN>	<N.NN>
2 SIDELOBE EXTENT (DEGREES)	<N.NN>	<N.NN>
3 SIDELOBE LEVEL (DB DOWN)	<NN.NN>	<NN.NN>

CLASSIFICATION

TO EDIT TYPE SIDELOBE NUMBER AND PRESS RETURN

TO EXIT TYPE 99 AND PRESS RETURN

FOR NEXT SCREEN PRESS RETURN

Page 3 Radar Parameters

CLASSIFICATION

ELNOT RADAR FILE PAGE 4 OF 5

THE NUMBER OF JAMMING MODES	N
1. J/S RATIO FOR <MODE> JAMMING IS	N.NN DB
2. J/S RATIO FOR <MODE> JAMMING IS	N.NN DB
3. (ETC.)	

CLASSIFICATION

TO EDIT TYPE LINE NUMBER AND PRESS RETURN

TO EXIT TYPE 99 AND PRESS RETURN

FOR NEXT SCREEN PRESS RETURN

Page 4 Radar Parameters

CLASSIFICATION

ELNOT RADAR FILE PAGE 5 OF 5

RADAR PARAMETRICS CURRENT AS OF <DD-MMM-YY>
COMMENTS LAST EDITED BY <NAME>
COMMENTS

1.
2.
3.
4.
5.

CLASSIFICATION

TO EDIT NOTES TYPE Y AND PRESS RETURN
TO EXIT TYPE 99 AND PRESS RETURN
TO GO TO PAGE ONE PRESS RETURN

Page 5 Radar Parameters

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